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J. R. Butler

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SOUTHEASTERN GEOLOGY

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Vol. 5, No. 4

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HYDROGEOLOGIC FRAMEWORK OF THE GULF AND ATLANTIC COASTAL PLAIN*

by

Harry E. LeGrand
U. S. Geological Survey

ABSTRACT

The Gulf and Atlantic Coastal Plain of the United States is underlain by an immense prism of Mesozoic and Cenozoic deposits that form a ground water system which is simple in general terms but complex in detail. Sand and limestone aquifers and alternating clay beds have a gentle coastward homoclinal dip and are ideally suited to the occurrence of artesian water.

The shallow subsurface part of the Coastal Plain contains in aggregate many thousands of cubic miles of fresh water in transient storage. A much greater volume of salty water in quasi-permanent storage underlies the fresh water as a wedge that thickens coastward. Except in southwest Texas, where the climate is not humid, most ground water recharge is short-circuited to effluent stream valleys through the water table and uppermost artesian aquifers.

By applying hydrologic principles to pertinent features of topography, geologic structure, lithology, and geologic history, it is possible to develop hydrogeologic classifications of the Coastal Plain that are useful. A new interest in systematics is leading to improved extrapolation and better understanding of the hydrology.

A water table aquifer and at least one artesian aquifer are present almost everywhere. The Coastal Plain has more immediate potential for ground water development than any other province of comparable size in the Western Hemisphere.

INTRODUCTION

The Atlantic and Gulf Coastal Plain is underlain by an immense hydrologic system which has more immediate potential for development of ground water resources than any other province of comparable size in the Western Hemisphere. Thousands of separate studies relating to the geology or to the ground water hydrology of local parts of the region have been made, but few attempts have been made to synthesize the results of separate studies. This paper is a brief summary of the

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hydrogeologic framework of the region and of ground water conditions in it.

The hydrologic system is controlled primarily by (1) the structural geology of the region, (2) diagenesis, (3) topography, and (4) climate. Some pertinent aspects of each of these major factors are discussed, followed by a discussion of integrated aspects of these factors as related to ground water occurrence and movement in the region. The final section of the paper contains some significant points about the hydrogeology of the Coastal Plain.

STRUCTURAL GEOLOGY

The Atlantic and Gulf Coastal Plain of the United States forms a broad belt that extends from Long Island southward along the Atlantic coast and westward along the Gulf coast to the Rio Grande. Murray (1961) has made a significant synthesis of many separate geologic contributions of the Coastal Plain.

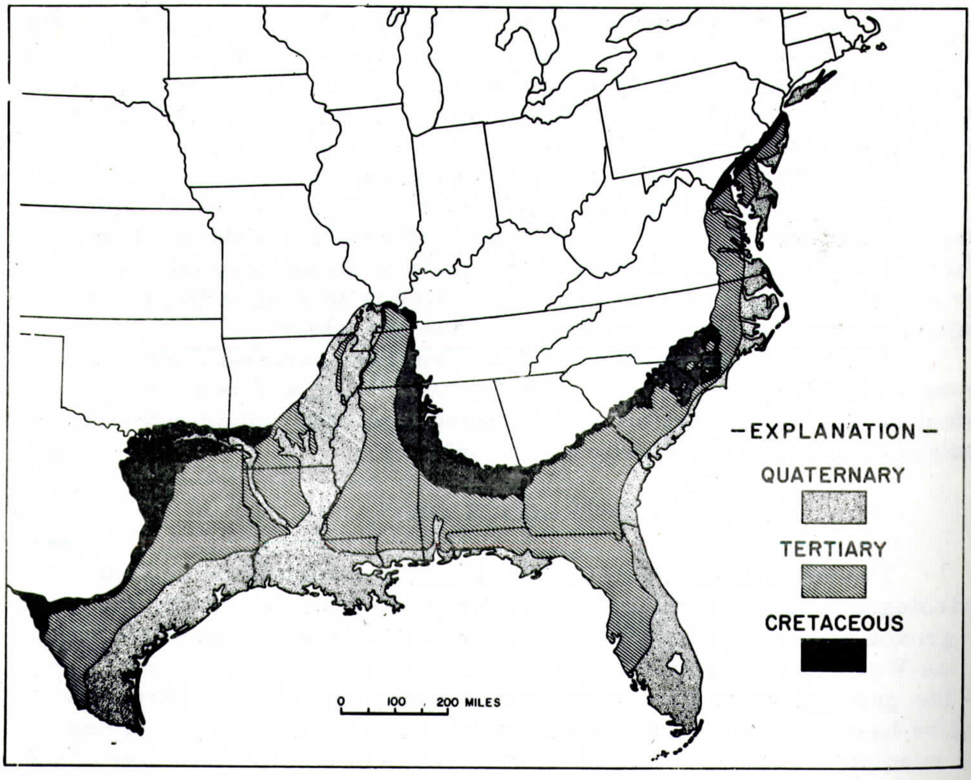

Figure 1. Approximate surface distribution of Cretaceous, Tertiary, and Quaternary units.

The plain slopes gently to the sea, extending beyond the coast line as the Continental Shelf. Beneath the plain, beds of sand, clay, and limestone of Cretaceous, Tertiary, and Quaternary age dip seaward. Figure 1 shows the general surface distribution of the Cretaceous, Tertiary, and Quaternary units. In gross terms the beds dip coastward at a rate only slightly greater than the slope of the land surface. Beds tend to thicken seaward. Many beds occurring at depth near the coast tend to wedge out before reaching the land surface at inland places. Figure 2 shows the altitude below sea level of the basement surface. Basement rocks are chiefly dense crystalline rocks and Paleozoic sedimentary rocks.

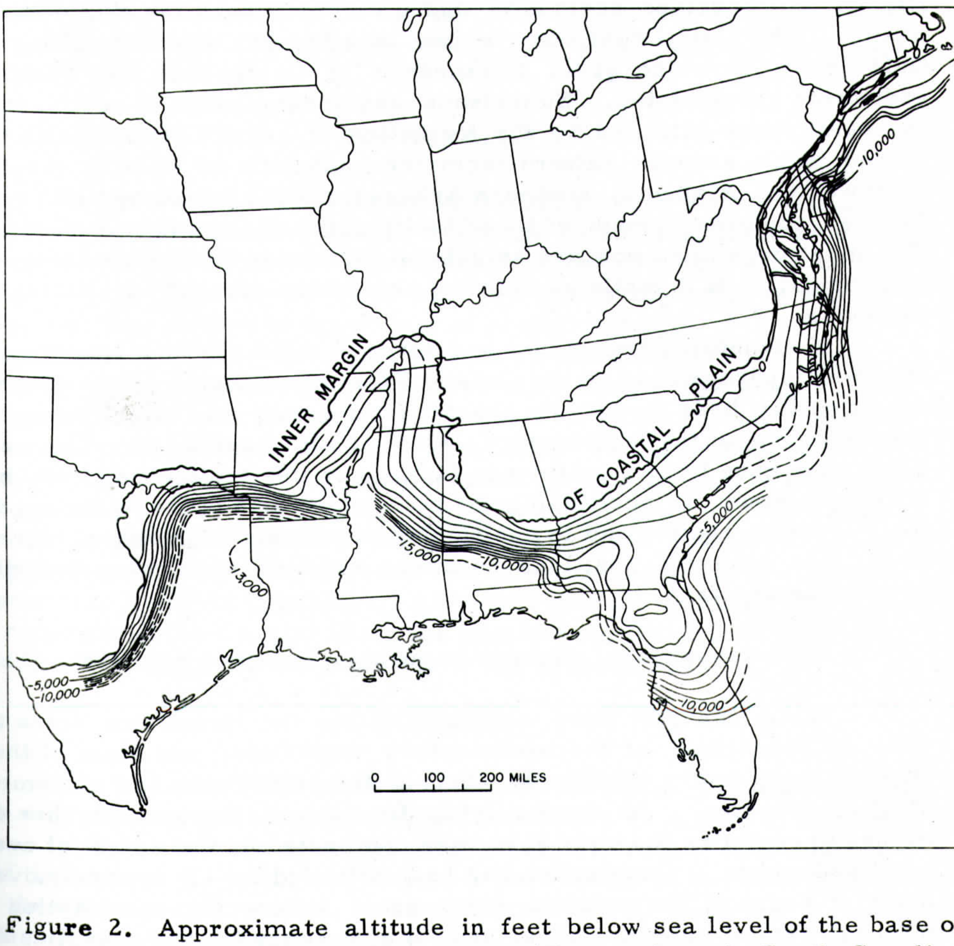

Figure 2. Approximate altitude in feet below sea level of the base of Coastal-Plain formations (Texas through South Carolina after Murray (1957) and North Carolina through New Jersey after Spangler and Peterson (1950).

The most striking gross structural features of the Coastal Plain are (1) the seaward dip of the beds, (2) a coastward increase in the thickness of individual beds, (3) a coastward increase in the number of beds, and (4) alternation of beds of different degrees of permeability. The beds commonly dip only a fraction of one degree. There are many departures from the gentle homoclinal dip, some beds exhibiting depressed, or negative, features and other beds exhibiting uplifted, or positive features. Most of the anomalous structures are in the Gulf Coastal region. The Mississippi embayment and the Gulf Coast Geosyncline have the most widespread significance. The Mississippi embayment is a downwarped and down-faulted trough in Paleozoic rocks extending northward along the course of the Mississippi River. Cretaceous and Tertiary seas extended as far north as southern Illinois and received sediments that now dip toward the center of the basin. The Gulf Coast Geosyncline is a trough, extending along the Gulf Coast, in which great thicknesses of Cretaceous and Tertiary sediments accumulated. Subsidence and accumulation of sediments in the basin were attended by the formation of gravity strike faults that extend in an arcuate pattern from the panhandle of Florida through southwestern Alabama, southern Arkansas, and a broad belt of Texas. Another complex system of these faults occurs in southern Louisiana. The most prominent positive structural feature is the peninsular uplift of Florida; it is a gentle arch in the sediments, almost paralleling the peninsula.

If structural departures are borne in mind, an understanding of the gross hydrogeology of the Coastal Plain must center on the general condition that beds tend to dip coastward at a rate only slightly greater than the slope of the land surface, which is also coastward. This condition may have little significance for local water-table conditions, but it is paramount in positioning belts in which an aquifer is the uppermost artesian aquifer and in positioning deeper artesian zones. Moreover, this condition positions recharge and discharge characteristics of artesian aquifers.

Post-depositional changes in porosity and permeability

Many changes have occurred within the formations since the time of deposition of the sedimentary materials, and some of these changes have had a significant effect on the occurrence and movement of ground water. In deeper-lying formations the porosity has decreased greatly as the beds have been compacted by the weight of overlying sediments. Compaction has been attended by (1) upward movement of some of the original formational water, (2) cementation of mineral grains in some cases, and (3) a tendency toward consolidation of sedimentary materials. Where the formations are deeper than about 3,000 feet porosity and permeability commonly are much less than in similar lithologic units of shallow depth.

Wide ranges in the porosity-permeability characteristics of calcareous materials occur within the Coastal Plain. Although some Pleistocene and Recent calcareous materials have remained unconsolidated, as have some older marls and chalks that have never been deeply buried, most of the calcareous materials have been consolidated into limestones and dolomites. Where these rocks have been elevated at some time in their history, so that meteoric water could circulate in them, solution has developed secondary permeability in the form of cavities. For example, parts of the Tertiary limestone unit of Florida, representing several formations, have been subjected to circulating ground water and to the enlargement of pore and channel openings during Pleistocene and Recent times (Stringfield, 1950, p. 221). Some deeply buried limestone formations of the Coastal Plain have never been above sea level and have never had meteoric water circulating through them; these rocks are still relatively dense and impermeable.

TOPOGRAPHY

Topography is a vital factor in the occurrence and movement of ground water because it controls recharge to and discharge from the underground water system. Moreover, features of topography provide differences in hydrostatic head between points of recharge and discharge and thus cause the movement of ground water.

From a broad view, the surface of the Coastal Plain appears nearly level, sloping only a few feet per mile toward the sea. Consequent streams have extended their courses seaward and represent the trunk streams toward which subsequent and insequent streams drain. Streams have cut their channels easily into the nearly flat-lying sand and clay beds. Bordering flood plains are common, but relief is generally significant between the flood plains and the upland areas. Along the coastal and central belts flat interstream areas are characteristic, and relief is appreciable only near stream valleys. Along the inner margin of the Coastal Plain the innerstream areas are more dissected, and slightly hilly topography is not uncommon there.

CLIMATE

The Coastal Plain east of the 95th meridian of longitude (in eastern Texas) receives an average of more than 40 inches of precipitation. In this humid region the precipitation is rather evenly distributed throughout the year, and in only a few months of the year is there less than 2 inches of rainfall. On the other hand, near the Mexican border in southern Texas, average precipitation is scarcely 20 inches a year; in that part of Texas, precipitation is about equal to the amount which, over the nation as a whole, is returned to the atmosphere annually by evapotranspiration.

The distinction between the humid and arid parts of the Coastal Plain is important. The humid region is characterized by effluent streams, which receive ground-water discharge from the zone of saturation in the interstream areas. In contrast, the arid region is characterized by influent streams which lose water into a deeper-lying zone of saturation. Thus, the ground water flow system is significantly controlled by climate.

OPERATION OF THE GROUND WATER RESERVOIRS

The sedimentary rocks of the Coastal Plain constitute an immense hydrologic system which is simple in general terms but complex in many details. The alternating layers of permeable and relatively impermeable beds, and their gentle homoclinal dips, are ideally suited to the occurrence of artesian aquifers at depth and of a near-surface water table aquifer. The aquifers (commonly medium to coarse-grained sands or limestones) and intervening impermeable beds (commonly clays or shales) vary greatly in thickness and areal extent. Some geologic formations contain several aquifers and several impermeable layers, whereas others compose only a part of an aquifer. For example, both the Magothy Formation of New Jersey, Delaware, and Maryland and the Black Creek Formation of the Carolinas contain at least two sand aquifers and two clay aquicludes. Many aquifers are separated by beds that are lenticular and that are not altogether impermeable. Thus, there is a considerable leakage between many aquifers where there is a difference in head between them.

The volume of water originally entombed in the sediments of the Coastal Plain was many hundreds of thousands of cubic miles. Most of it was sea water. The volume of water has decreased and the quality has everywhere been altered. The weight of many hundreds or many thousands of feet of overlying sediments caused water from the deeper sediments to be squeezed upward as the pore space was reduced. The storage capacity and permeability of deep-lying sediments, therefore, are now relatively low.

Much of the precipitation infiltrates into sandy surface soils, although some finds its way into rivers, creeks, and ditches immediately after each rain. Some water evaporates immediately, whereas some seeps into the soil where it is held only to be evaporated or transpired by vegetation. If the rain is prolonged some water passes below the root zone; a part is impeded in its downward movement by clay beds and is shunted laterally, even above the water table, to a steep slope where it is evaporated; some of the water moves downward to the water table, which is the top of the zone in which the openings in the rock materials are saturated with water. Upon reaching the water table it becomes ground water. This is not a final resting place because the ground water in the Coastal Plain moves by gravity to some low place where it discharges from the earth materials. The movement may be extremely slow if impediments are in its path or if avenues for escape are poor. Ground water discharges naturally (1) as evapotranspiration in low areas,(2) as seeps and springs which tend to sustain the flow of streams in long periods of fair weather, and (3) as leakage into marginal seas.

The depth to the water table depends on the frequency and intensity of precipitation, on the ability of earth materials to transmit water, and on topography. Where a humid climate prevails, as in all of the Coastal Plain except the southern part of Texas, the frequency of periods of precipitation causes the water table to be near the land surface, especially in the low, flat areas (Fig. 3). In the humid part of the Coastal Plain the water table has a higher elevation beneath the upland, or interstream areas, than in the stream valleys; as a result, ground water moves toward the valleys and discharges into the streams. In the arid part of the Coastal Plain the scarcity of precipitation keeps the water table at a relatively low stage; water from parts of many streams seeps downward, adding water to the zone of saturation and building up the water table beneath the streams. Where poorly permeable materials, such as clay, sandy clay, or fine sand, and relatively flat topography exist, the water table is within a few feet of the land surface in the humid part of the Coastal Plain; this is a common condition. Where permeable materials such as coarse sand or limestone underlie the surface of hilly topography, the water table may lie 40 feet or more below the ground.

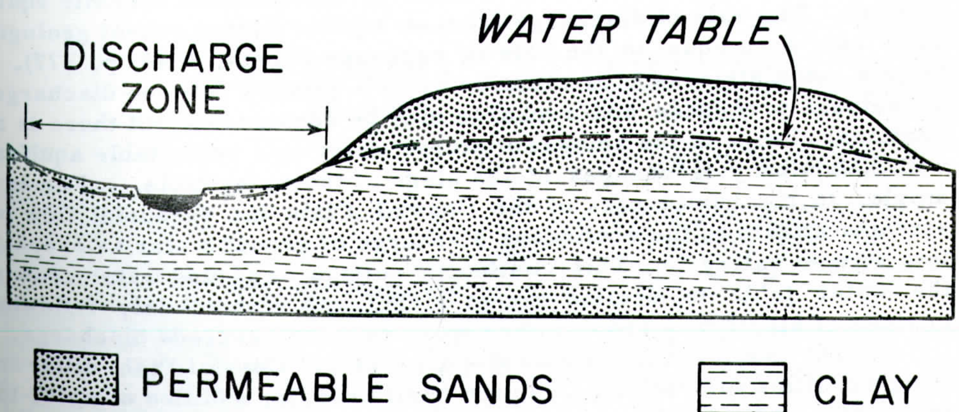

Figure 3. Diagram showing relative position of the water table beneath upland areas and in the discharge zone of a stream valley.

At some place below the water table a relatively impermeable bed occurs which retards the further downward movement of water. This impermeable bed, commonly clay, acts to confine under pressure the water that lies beneath it. The water enters the ground, reaches the water table, and flows

". . . down with the slope of the water table to a point where the zone of saturation is interrupted by an impermeable bed. Part of the water may pass above the bed and continue to flow under water table conditions, and part of it flows beneath the bed. Now it is confined, pressing upward against the impermeable bed with a head equivalent to the difference in elevation between that point and the elevation of the water table in the area of recharge, less the loss of head resulting from friction in movement. This is confined or artesian water; it will rise in a tightly cased well to a height above the bottom of the confining bed equivalent to the pressure head at that point. If the head happens to be above the land surface, as it commonly is in the valleys or along the coast . . ., the well will flow." (McGuiness, 1951, p. 12-13).

Water fed to an artesian aquifer generally passes first through a water table aquifer that acts as a regulator to accept or reject water according to certain conditions. Recharge results from the infiltration of precipitation through the soil to the water table, or, in the case of south Texas where the precipitation is slight, by seepage downward from some streams. Discharge occurs as liquid outflow and by evapotranspiration. Under natural conditions, beyond the influence of pumped wells, aquifers are in a state of approximate dynamic equilibrium. The rate of discharge from an aquifer during recent geologic time has been equal to the rate of recharge (Theis, 1940, p. 277). Over a complete season or climatic cycle a balance between discharge by natural processes and recharge may be considered, but there is a continual change in the amount of stored water in a water-table aquifer, with accompanying changes in the stage of the water table. For example, in the humid part of the Coastal Plain the perennial flow of streams attests to the continuous discharge of ground water as seepage into stream valleys. This continuous outflow of ground water causes the water table to decline except during and immediately following periods of significant precipitation when recharge exceeds discharge.

The humid and semiarid parts of the Coastal Plain differ in their facilities for recharge. In the humid region, addition of water to the water table aquifer during most of the year, but especially during wet seasons, keeps the water table at a high stage in the interstream, or recharge, areas. In this case, the aquifer becomes over-full and potential recharge is rejected (Theis, 1940, p. 278); the excess water leaks out into the valleys as seeps and springs or builds up the zone of saturation to a level near the land surface where water is lost to evaporation and transpiration (Barksdale and others, 1958, p. 42). In the less humid part of the Coastal Plain, in south Texas, the water table is normally below the bottoms of many streams. Here almost all water that infiltrates through surface materials is accepted by the aquifer, and the possible rate of recharge may be less than the rate at which the aquifer could accept the water and carry it away.

To some extent each artesian aquifer of the Coastal Plain acts as a pipe or conduit, transmitting water from a place of recharge at a high elevation to a place of discharge at a low elevation. The analogy soon breaks down because most aquifers in their downdip and coastward parts are less permeable than farther inland, are filled with dense mineralized water, and have extremely poor facilities for discharging water at great depths. Therefore, water in these aquifers tends to move upward, even through relatively impermeable aquicludes, into aquifers which have lower hydrostatic pressure. Some water discharges into the sea, and some moves upward through aquicludes and aquifers to reach a stream or the water-table aquifer. In places streams cut into artesian aquifers and bleed water from them; even where relatively impermeable beds separate the uppermost artesian aquifer from a stream, upward leakage to the stream valley may be considerable (Fig. 4). Recharge from the water-table aquifer to the uppermost artesian aquifer occurs when and where the water table is higher than the pressure surface of the artesian aquifer. In many parts of the Atlantic and Gulf Coastal Plain the water table and the pressure surface of the uppermost artesian aquifer have about the same elevation on the upland, or interstream, areas. As the water table aquifer is recharged the difference in head between the aquifers

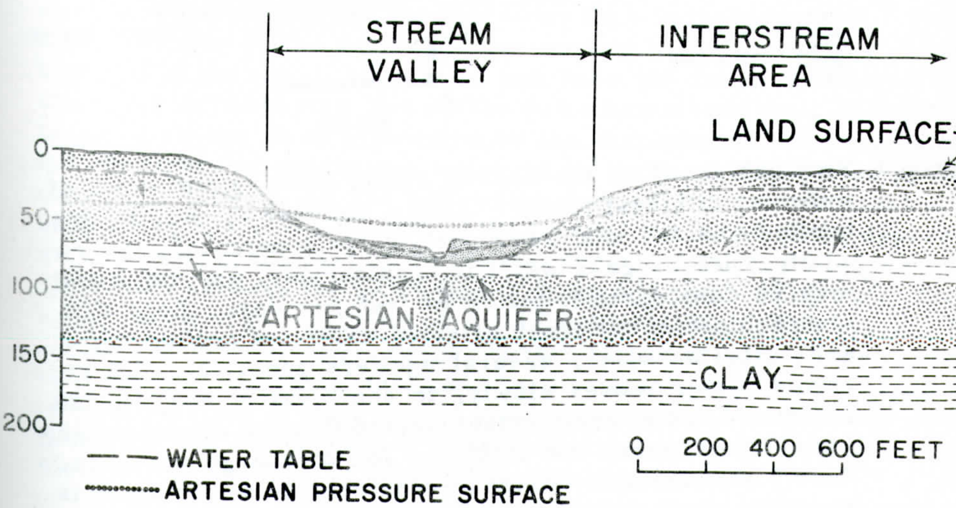

Figure 4. Diagram showing relative positions of the water table and piezometric surface of the uppermost artesian aquifer beneath stream valley and interstream area and the movement of water between these aquifers.

is increased and water moves slowly downward through relatively impermeable materials to the artesian aquifer (Fig. 4).

How fast does ground water move in the Atlantic and Gulf Coastal Plain? It has long been known that the rate of flow is directly proportional to the hydraulic gradient, which is the difference in head between two points divided by the distance between them. The hydraulic gradient tends to steepen, and consequently, the rate of flow tends to increase, near areas of discharge. Thus the rate of flow in the water-table and uppermost artesian aquifers tends to increase in the vicinity of stream valleys. The rate of flow also increases around wells that yield water. The movement also depends on the character and structure of the rocks, for ground water flows in permeable materials and between or around impermeable ones. We may conveniently take vertical sections through the Coastal Plain and dis-

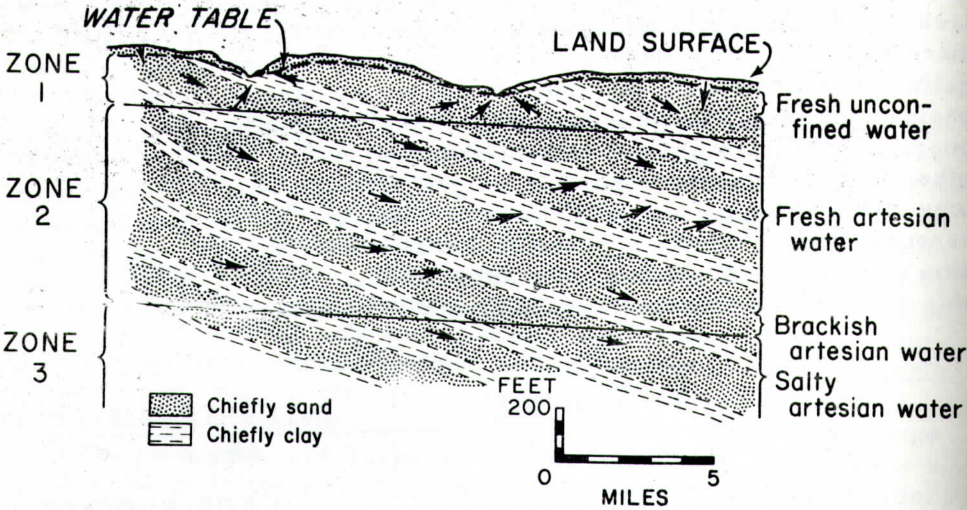

Figure 5. Vertical zones of the Coastal Plain, showing movement of water at different rates. Zone 1 includes the water-table aquifer and the shallower part of the uppermost artesian aquifer; discharge of water is considerable, and movement may be considered in terms of feet per day. Zone 2 includes most of the fresh artesian water and perhaps some salty artesian water, several aquifers generally being involved; water moves slowly, to some extent downdip and coastward and to some extent upward through relatively impermeable layers, but facilities for discharge are poor. Zone 3 contains salty water at considerable depth; water is so confined that movement may be considered in terms of feet per century. The thickness of each zone may vary considerably from place to place.

tinguish three zones in which water moves at different rates. In zone 1 of Figure 5 the water table and uppermost artesian aquifers are incised by streams, resulting in relatively rapid movement of water to the streams. The zone may be considered as extending 100 or 200 feet beneath the base of the streams, and the rate of movement may be considered in terms of feet per day to feet per year. The base of zone 2 is also arbitrary and may be considered to extend to a depth of several hundred feet or perhaps to a depth at which the water is salty; the water in zone 2 has no good discharge facilities and its rate of movement may be considered generally in terms of feet per year. Zone 3 contains only salty water and has extremely poor facilities for discharging water; the rate of movement may be considered in terms of feet per century. It must be realized that withdrawal of water from wells, or introduction of fluids through wells, would steepen the hydraulic gradient and would greatly quicken the flow in any of the zones.

CHEMICAL CHARACTER OF THE WATER

The chemical character of water in the Coastal Plain ranges from that of some near-surface water of low mineralization, containing less than 25 parts per million of total dissolved solids, to that of some deeply buried brines whose total dissolved mineral content is several times that of sea water. Sea water contains about 35,000 parts per million of total dissolved solids, of which slightly more than 19,000 parts are chloride ions and more than 10,000 are sodium ions.

Almost all of the sediments were deposited in sea water or had sea water introduced into them at some time in their history. Yet almost nowhere do the sediments now contain water chemically identical with that of the sea. Movement has been the cause of changes in the character of the water, for all the water has moved some distance and in doing so has been influenced by the character of sediments and by the character of contiguous water in its path. Water from precipitation has flushed out the salt water formerly present in most of the beds along the inner margin of the Coastal Plain and in the uppermost beds in most of the rest of the coastal areas. Thus, we must make a distinction between the water that is fresh and potable and water that is salty. Most of the saltiness is due to sodium and chloride ions. Two exceptions include some deeply buried brines that have more calcium than sodium and some water of intermediate depth in south Texas that is relatively low in chloride but high in calcium and magnesium sulfate. However, for the purposes of this report, water containing less than 500 parts per million of chloride is considered fresh.

As water moves through the Coastal-Plain sediments toward a place of discharge it changes in chemical character, in most cases becoming more mineralized with distance and time of travel. Some of the changes are evolutionary and may be traced in a general way. In all the Coastal Plain except south Texas, almost all of the water below the water table has passed downward through rather insoluble and leached sands and clays. The water table aquifers are generally composed of sands containing very little soluble material. Thus, much shallow ground water is characterized by low total dissolved solids, considerable free carbon dioxide, and a pH value ranging from 5.0 to 7.0. Where the water-table aquifer is limestone, as in the northwest part of the peninsula of Florida, the water quickly dissolves the limestone and increases in calcium bicarbonate content. Some waters increase in calcium bicarbonate content as they move certain distances through sandy artesian aquifers. However, Foster (1942, p. 838) and Cederstrom (1945, p. 99) have shown that because of the ion-exchange capacities of some clays and glauconite, movement farther downdip and coastward tends to soften the water because calcium from the water is exchanged for sodium of the earth materials. Belts of soft, sodium bicarbonate water from artesian sand aquifers occur especially in Virginia, North and South Carolina, Alabama, and Mississippi. Hard, calcium bicarbonate water is characteristic of limestone aquifers; all of the fresh artesian water of peninsular Florida is of this type. In

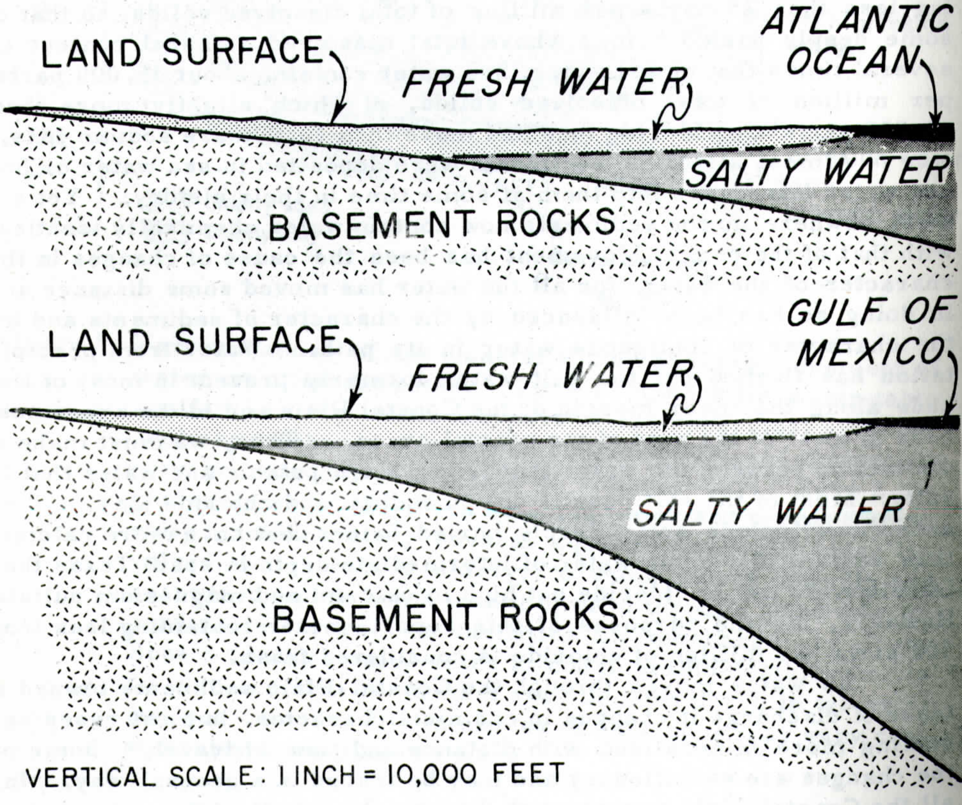

Figure 6. Generalized position of the fresh-water zone relative to position of salt-water zone in the Atlantic and the Gulf Coast.

south Texas the fresh ground water is somewhat more mineralized than in other parts of the Coastal Plain province; in this area many of the public and individual supplies deliver water containing 1000 parts per million of dissolved solids (Broadhurst and others, 1950, p. 2).

The zone of fresh water overlies the zone of salt water throughout the Coastal Plain province, but in a few places lenses of fresh water may be found below lenses of salty water. Generally the depth to salty water is greater beneath high inland places than beneath low coastal places (Fig. 6). Along the inner margin of the Coastal Plain all the beds may contain fresh water, whereas along the coast only the uppermost beds contain fresh water. South Carolina appears to be the only coastal State which contains a greater proportion of fresh water than salt water; Delaware contains nearly as much fresh as salty water. Florida and Louisiana contain large volumes of fresh water, but because the sediments in these States are extremely thick and extend far below sea level the volume of fresh water is much less than that of salt water. The surface of the salt-water body is very irregular, and information is not yet adequate in most States to map it with reasonable accuracy.

HYDROGEOLOGIC CLASSIFICATION OF THE COASTAL PLAIN

It is postulated that a hydrogeologic classification of the Coastal Plain is needed for us (1) to see and remember significant features of the hydrology, (2) to adequately synthesize our knowledge, (3) to see pertinent relationships, and (4) to develop predictions of hydrologic phenomena that will be useful in practices of water and waste management. It has been noted that hydrologic conditions result chiefly from the interaction of climate, topography, geologic structure, time, and certain actions of man; wherever these factors are similar, the hydrologic conditions are similar. Although hydrologic complexities and geologic heterogeneities are fairly common, especially in detailed analysis, one must admit that certain groups of hydrologic features showing similarities and differences can be synthesized into a harmonious whole. By fully developing a hydrogeologic classification of the Coastal Plain, he can construct hypothetical pictures of hydrologic conditions at any place in the Coastal-Plain framework. These hypothetical pictures without additional data will be sufficient for many purposes; for cases in which additional data are needed, one has the framework on which to hang details, and he can collect pertinent data without being blinded by a host of trivialities and by a superabundance of extraneous data. Specific geologic and hydrologic studies will continue to be necessary, but there is a need to improve techniques of developing the principle of successive approximation - getting the best possible answers today and improving or refining them tomorrow if necessary.

In a hydrogeologic classification of the Coastal Plain, certain groups of elements in the environment appear to be important. Per-

Table 1. Classification of Natural Recharge and Discharge Conditions

Phase in ground water circulation

1. Predominant recharge - insignificant discharge.
   Example - (artesian) - lake region of central Florida.
   - (water table) - interstream sand-hill areas of Georgia, South Carolina, and North Carolina.
2. Significant recharge - variable discharge.
   Example - (artesian) - upland outcrop belt of artesian aquifer.
   - (water table) - upland hillslopes in humid part of Coastal Plain.
3. Recharge and discharge vary locally and with time so that they tend to offset each other.
   Example - (artesian and water table) - some parts of aquifer between main recharge and main discharge points.
4. Predominant discharge - subordinate recharge. (some net discharge)
   Example - (artesian) - on-shore coastal areas where artesian water moves upward into water table aquifer.
   - (water table) - some flood plains and lower slopes in humid part of Coastal Plain.
5. Predominant discharge - insignificant recharge.
   Example - (artesian) - off-shore discharge into sea.
   - (water table) - stream channel in humid part of Coastal Plain.

Degree

A. Appreciable recharge or discharge.
B. Moderate recharge or discharge.
C. Inappreciable recharge or discharge.

Source

I. Recharge from precipitation.
II. Recharge from underflow.
III. Discharge from evapotranspiration.
IV. Discharge into streams.
V. Discharge into large bodies of water.

haps the first apprehension in considering a classification system is that one should not go beyond the realm of empirical associations and correlations to the extent that the future be prejudiced (Bridgman, p. 37) or the possibilities of new findings be limited; conceding the need for caution, one must recognize the overriding need to organize our ideas in ways that are useful. In this paper it will suffice to mention briefly certain groups of ideas and features of the hydrogeologic environment that seem to lead to a better understanding of the Coastal

Plain. Such groups include vertical and areal zonations in the hydrogeologic system, lineation of natural discharge zones, topographic situations relating to recharge and discharge, and various discharge and recharge patterns.

The tendency for vertical zonation of ground water is shown in Figure 5. Areal zonation, such as (a) the inner margin of the Coastal Plain, (b) intermediate areas, and (c) the coastal margin, also seems useful. For example, relatively great topographic relief along the inner margin of the plain tends to cause relatively rapid movement of water in the water-table and uppermost artesian aquifer, and this freely circulating water is not saline. Along the coastal margin, in contrast, the aquifers generally have no good natural discharge facilities, resulting in sluggish movement and the entrapment of much salty water in the artesian aquifers.

Natural ground water discharge occurs from the water-table and the uppermost artesian aquifers. This discharge is predominantly from linear zones in consequent, subsequent, and insequent stream valleys. The gentle coastward dip of the formations in relation to the even more gentle coastward regional land slope results in discharge patterns from the uppermost artesian aquifers in the vicinity of consequent streams that are distinctly different from those near subsequent streams. Hypothetical piezometric surfaces can be constructed for the uppermost artesian aquifer that should have much potential value in the future water development and management in the region. A description of ground water discharge in consequent streams is now in preparation.

Although no attempt is made here to elaborate on the various means of ground water discharge in the region, the following categories of discharge give us insight into the great hydrologic system of the Coastal Plain:

1. Consequent streams into which the water-table and uppermost artesian aquifers discharge water and in the vicinity of which the piezometric surfaces of the two aquifers have special patterns. (Typical of inner parts of Coastal Plain. Since stream channel is in same direction as dip, balanced ground water discharge may be expected from both sides of stream. Outcrop of uppermost artesian aquifer in stream channel is lower in elevation and is nearer coast than on upland interstream area, resulting in much of the confined water beneath interstream area taking a downdip and coastward direction before taking a circuitous course updip and inland to discharge in stream where the overlying confining bed is cut away).

2. Subsequent streams into which the water-table and uppermost artesian aquifers discharge water and in the vicinity of which the piezometric surfaces of the two aquifers have special patterns. (Typical of inner parts of Coastal Plain. Since the stream channel is normal to dip, entrenchment of stream into artesian bed causes unbalanced artesian discharge beneath the surface drainage slopes and results in asymmetrical piezometric contours. Artesian leakage may

be considerable from updip slope and slight from downdip slope.)

3. Insequent streams, which may resemble a combination of consequent and subsequent streams.

4. Flat terrain with slight incision into the water-table aquifer. Recharge potential may be great but is likely to be offset by increased discharge through evapotranspiration. Diffused artesian leakage upward into the water table aquifer in coastal areas.

5. Water table discharge into the marginal sea.

6. Submarine artesian discharge from the Continental Shelf or slope.

7. Pumping of wells.

Table 1 shows a generalized classification of natural recharge and discharge conditions. Ground water maps on which recharge and discharge conditions are delineated should be feasible and useful in many cases.

SUMMARY

Homoclinal coastward-dipping beds of the Atlantic and Gulf Coastal Plain are ideally suited for the occurrence of artesian water. Water is confined under pressure beneath clays and other relatively impermeable beds. The permeable beds, or aquifers, are commonly sands and limestones. The interlayering of relatively thin to moderately thick impermeable and permeable beds results in several separate artesian aquifers where the sediments are thick. Deep-lying artesian water is confined so well that it has no means of escaping readily; therefore, its natural circulation may be so slow that the rate of movement may be considered in terms of a few feet per year or, more likely a few feet per century. The uppermost artesian aquifer commonly is separated from the near-surface water-table aquifer by an impermeable layer. Water moves vertically, even through seemingly impermeable beds, so that there is a slow movement of water between aquifers--from one of higher head to one of lower head. The uppermost artesian aquifer is an important distributor of water for the entire artesian system; some of its water discharges into stream valleys, and in many places some of it discharges into the water table aquifer. In most places the head of the deeper aquifer is greater than that of its overlying aquifer. Water tends to have both a downdip and an upward component of movement in the artesian aquifers, but there are many exceptions to this tendency.

The water table in flat, low areas is commonly within a few feet of the land surface. Places where the water table lies within 30 feet of the land surface are extremely common, and places where it lies below 100 feet are relatively scarce. There are no dry openings or dry caverns at great depth.

Almost all the sand and clay, and some of the calcareous material no deeper than 1,500 feet, are unconsolidated. With increasing depth, especially below 3,000 feet, many beds are consolidated. The deep-lying beds generally have finer-grained material than their inland and shallow counterparts. Thus, the permeability of the deep-lying beds almost invariably is less than that of beds near the surface.

Calcareous materials occur as limestone, marl, chalk, and finely dispersed materials in some sands and clays. North of North Carolina calcareous material is scarce. Limestone and other carbonate rocks compose the bulk of sediments of Florida. Limestone occurs elsewhere in scattered formations near the land surface, and the amount of limestone tends to increase toward the coast with depth. The Tertiary limestone unit of Florida and Georgia contains many permeable beds, and other limestone formations show a wide range of permeability. Marls and chalks of South Carolina, Alabama, Mississippi, and Texas are noteworthy because of their relatively low permeability.

The basal sediments in the coastal regions contain salty water. In considering the entire volume of Coastal Plain sediments, the volume containing salt water greatly exceeds that containing fresh water. The contact between the fresh-water zone and the underlying salt-water zone is erratic and is not amenable to brief accurate description. In general, the deepest fresh-water zones are in the hinterland. The freshwater zone is somewhat lens-shaped in cross-section. At many coastal points it is less than 100 feet thick; at places in the hinterland it is several hundred feet thick; and along the inner margin it thins as the sediments thin in a feather-edge.

The largest streams flow completely across the Coastal Plain to the sea. These streams and their tributaries form the bulk of the drainage. All streams, except perhaps those in extreme southern Texas, are effluent or "gaining" streams, typically, the water table beneath the interstream areas is higher than the stream level, and ground water moves toward the valleys to contribute water to the streams. Throughout most of the Coastal Plain the valleys are incised in loose sands and clays which tend to disperse ground water discharge as seepage or small springs into streams. Only where limestone is the near-surface aquifer, as in the northwestern peninsula of Florida, are large springs noteworthy.

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THE PUNGO RIVER FORMATION, A NEW NAME FOR MIDDLE MIOCENE PHOSPHORITES IN BEAUFORT COUNTY NORTH CAROLINA *

by

Joel O. Kimrey
U. S. Geological Survey
Raleigh, N. C.

ABSTRACT

This paper proposes the designation, Pungo River Formation, for a previously unnamed phosphorite unit of middle Miocene age that underlies more than 700 square miles of Beaufort County, North Carolina.

The Pungo River Formation is composed of interbedded phosphatic sands, silts and clays, diatomaceous clays, and phosphatic and non-phosphatic limestones. The formation dips gently to the east in Beaufort County; its thickness ranges from a featheredge, a few miles east of the city of Washington,to more than 110 feet in the southeastern part of the county.

INTRODUCTION

The Ground Water Branch of the U. S. Geological Survey began a geology and ground-water investigation in Beaufort County, North Carolina in March, 1962. The purpose of the investigation was to evaluate the ground water resources of the part of the county underlain by phosphorite deposits and to delineate the phosphorite unit. The investigation was made by the U. S. Geological Survey in financial cooperation with the North Carolina Division of Mineral Resources and the Beaufort County Board of Commissioners. The fieldwork was done under the immediate supervision of P. M. Brown, District Geologist, and under the general supervision of O. M. Hackett, Chief, Ground Water Branch, U. S. Geological Survey.

The phosphorite unit in Beaufort County, North Carolina, was first formally described by Brown (1958). He designated the unit as being of middle Miocene age on the basis of Foraminifera from the upper part of the unit that are correlative with Foraminifera from the Calvert Formation of middle Miocene age in Maryland.

* Publication authorized by the Director, U. S. Geological Survey.

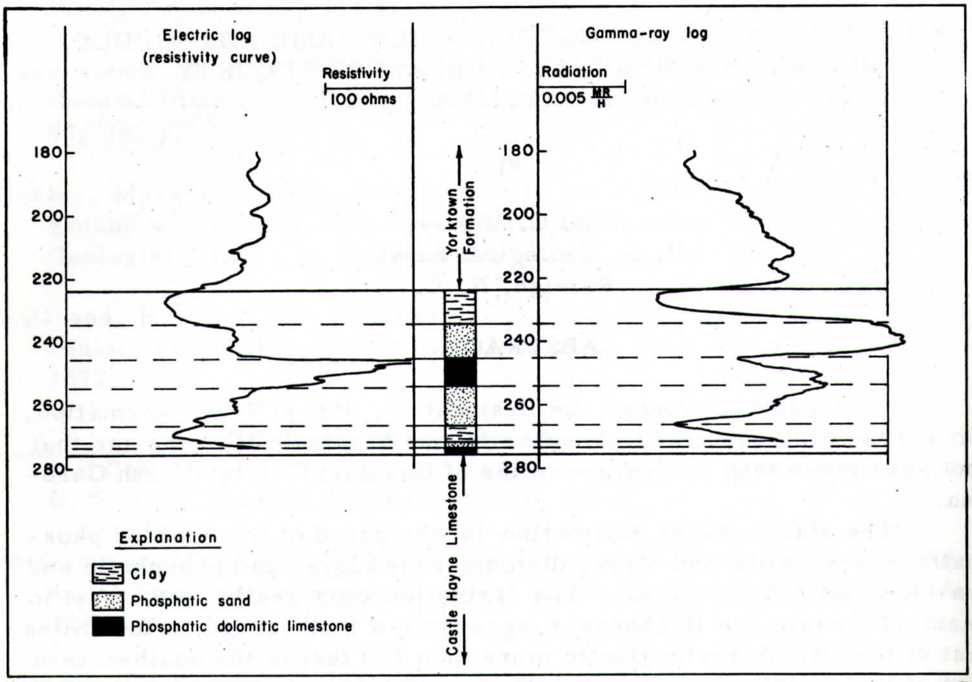


Figure 1. Electric and gamma-ray logs of the type core hole for the Pungo River Formation.

PUNGO RIVER FORMATION

Current economic interest in the phosphatic sands of the unit prompts the proposal of a formation name. Accordingly, this unit is here named the Pungo River Formation; the name is derived from the Pungo River in eastern Beaufort County. As the formation is not known to crop out, a core hole near Belhaven, in eastern Beaufort County, is designated as the type core hold. The coordinates of the type core hole are: longitude 76°34'59", latitude 35°35'58". The core hole was drilled in December, 1962, by the U. S. Geological Survey. Its land surface elevation is 10 feet above sea level, and 52 feet of middle Miocene strata were penetrated between the depths of 224 and 276 feet. Geophysical logs of the type core hole are shown in Figure 1. The lithology of the type section is described as follows:

Depth Interval	P_2O_5 Content (%)	Lithology
		Upper Miocene - Yorktown Formation: 10-224'
		Middle Miocene - Pungo River Formation
224'0"-224'8"	1.54	Clay, dark olive-green; Dark olive-green slightly calcareous clay. Trace of fine-

Depth Interval	P_2O_5 Content (%)	Lithology
		grained angular to subangular clear quartz sand, fine-grained dark-brown to black phosphate. Black clay prominent. This interval contains thin layers of light greenish-gray fine sand. Foraminifera abundant.
224'8"-225'7"	1.54	Clay, dark olive-green; Same as 224'0"-224'8" interval with no sand layers. Foraminifera common.
225'7"-226'7"	0.76	Clay, dark olive-green; Same as 224'8"-225'7" interval with Foraminifera rare.
226'7"-227'7"	0.76	Clay, dark olive-green; Dark olive-green calcareous clay. Trace of fine subangular to subrounded clear quartz sand. Foraminifera common.
227'7"-228'4"	0.76	Clay, dark olive-green; Same as 226'7"-227'7" interval with Foraminifera very abundant.
228'4"-229'4"	0.43	Clay, light olive-green; Light olive-green light-weight slightly calcareous clay. Trace of fine subangular to subrounded clear quartz sand. Foraminifera abundant.
229'4"230'4"	0.43	Clay, light olive-green; Same as 228'4"-229'4" interval with 10 percent of sample composed of diatoms. Foraminifera abundant.
230'4"-231'5"	0.43	Clay, light olive-green; 90 percent light olive-green light-weight slightly calcareous clay, 10 percent fine angular to subangular clear quartz sand. Foraminifera very abundant, diatoms rare.
231'5"-232'0"	5.22	Clay, light olive-green; 75 percent light olive-green light-weight slightly calcareous clay, 20 percent fine subangular to angular clear quartz sand, 5 percent fine-grained dark-brown to black phosphate. Foraminifera very abundant,

Depth Interval	P_2O_5 Content (%)	Lithology
		diatoms common.
232'0"-233'0"	5.22	Phosphatic sandy clay, dark olive-green; 50 percent highly calcareous dark olive-green clay, 30 percent fine- to medium-grained light-brown to black phosphate, 20 percent fine angular to subangular clear quartz sand. Trace of medium-grained dark-brown to black phosphate. The upper 6 inches of this interval contains spots and layers of light olive-green clay, same as 231'5"-232'0" interval. Foraminifera common.
233'0"-233'10"	5.22	Diatomaceous clay, light olive-green; 85 percent light olive-green light-weight slightly calcareous clay, 15 percent of sample composed of diatoms, most arranged in definite layers. Foraminifera common.
233'10"-234'5"	5.22	Diatomaceous clay, light olive-green; Same as 233'0"-233'10" interval with trace of fine subrounded clear quartz sand, fine-grained dark-brown to black phosphate. Foraminifera abundant.
234'5"-236'5"	14.5	Phosphatic sand and clay, dark greenish-brown; 45 percent fine- to medium-grained light-brown to black phosphate, 35 percent fine to medium subangular to subrounded clear quartz sand, 20 per cent greenish-gray clay. Trace of coarse subrounded clear to frosted quartz sand, coarse-grained dark-brown to black phosphate. Foraminifera abundant.
236'5"-237'5"	16.6	Phosphatic sand and clay, dark greenish-brown; Same as 234'5"-236'5" interval.
237'5"-238'5"	16.16	Phosphatic sand and clay, dark greenish-brown; Same as 236'5"-237'5" interval with Foraminifera rare.

Depth Interval	P_2O_5 Content (%)	Lithology
238'5"-239'4"	16.6	Phosphatic sand and clay, dark greenish-brown; Same as 237'5"-238'5" interval with no microfossils.
239'4"-240'4"	18.5	Phosphatic sand and clay, dark greenish-brown; Same as 238'5"-239'4" interval.
240'4"-241'4"	18.5	Phosphatic sand and clay, dark greenish-brown. Same as 239'4"-240'4" interval with 5 percent increase in fine to medium quartz sand and corresponding decrease in phosphate.
241'4"-242'4"	18.5	Phosphatic sand and clay, dark greenish-brown; Same as 240'4"-241'4" interval with trace of lignitized wood, amber.
242'4"-243'0"	19.8	Phosphatic sand, dark greenish-brown; 55 percent fine to medium angular to subangular clear quartz sand, 45 percent fine-grained light-brown to black phosphate. Light-gray weathered phosphate prominent. Trace of coarse-grained dark-brown to black phosphate, medium subrounded clear quartz sand, light- to dark-gray fragments of limestone. Foraminifera very rare.
243'0"-244'0"	19.8	Phosphatic sand, dark greenish-brow Same as 242'4"-243'0" interval with 10 percent increase in phosphate and corresponding decrease in fine to medium quartz sand. Foraminifera rare.
244'0"-245'8"	19.8	Phosphatic sand, dark greenish-brown; 45 percent fine- to medium-grained light-brown to black phosphate, 35 percent medium angular to subangular clear quartz sand, 20 percent fine angular to subangular clear quartz sand. Light-gray weathered phosphate and light-gray clay prominent. Trace of medium-grained dark-brown to black phosphate. Foraminifera very rare.

Depth Interval	P_2O_5 Content (%)	Lithology
245'8"-246'8"	4.59	Phosphatic sandy limestone, medium greenish-gray, 65 percent very fine crystalline well indurated medium-gray limestone, 20 percent medium angular to subangular clear quartz sand, 15 percent fine- to medium-grained light-brown to black phosphate. Foraminifera rare.
246'8"-248'10"	4.52	Phosphatic sandy limestone, medium greenish-gray; Same as 245'8"-246'8" interval with no microfossils.
248'10"-259'7"	4.52	No sample.
259'7"-259'10"	7.50	Phosphatic sandy limestone, medium greenish-gray; Same as 246'8"-248'10" interval.
259'10"-260'10"	13.7	Phosphatic sand and clay, light greenish-gray; This interval consists of alternating layers of clay and phosphatic sand. For entire interval: 65 percent very fine to fine angular to subangular clear quartz sand, 15 percent light greenish-gray clay, 15 percent very fine- to fine-grained light-brown to black phosphate, 5 percent medium-grained light-brown to black phosphate. Medium subangular to subrounded clear quartz sand prominent. Trace of light-gray limestone particles, very fine-grained light-green glauconite. Foraminifera and sponge spicules very rare.
260'10"-262'8"	13.7	Phosphatic sand and clay, light greenish-gray; Same as 259'10"-260'10" interval with Foraminifera very rare.
262'8"-263'8"	10.6	Phosphatic sand and clay, light greenish-gray; Same as 260'10"-262'8" interval with 15 percent increase in light greenish-gray clay and corresponding decrease in fine quartz sand. Diatoms and sponge spicules common, no Foraminifera.

Depth Interval	P_2O_5 Content (%)	Lithology
263'8"-264'8"	10.6	Phosphatic clay and sand, light olive-green; Alternating irregular layers of light olive-green clay with layers of phosphatic sand. For entire interval; 55 percent light olive-green clay; 25 percent very fine- to fine angular to subangular clear quartz sand, 15 percent very fine- to fine-grained light-brown to black phosphate, 5 percent medium-grained light-brown to black phosphate. Trace of medium subrounded to rounded clear quartz sand. Small Foraminifera, diatoms, sponge spicules rare.
264'8"-265'8"	10.6	Phosphatic clay and sand, light olive-green; Same as 263'8"-264'8" interval with 5 percent increase in medium quartz sand and corresponding decrease in fine-grained phosphate. Diatoms and sponge spicules rare.
265'8"-266'8"	1.36	Phosphatic sandy clay, light olive-green; 75 percent light olive-green slightly calcareous clay, 15 percent very fine- to fine-grained angular to subangular clear quartz sand, 10 percent very fine- to fine-grained light-brown to black phosphate. Medium subangular to subrounded clear quartz sand and medium-grained dark-brown to black phosphate prominent. Trace of rose quartz, medium broken shell fragments. The sand and phosphate in this interval occur in thin layers. Diatoms rare.
266'8"-267'9"	1.36	Phosphatic sandy clay, light olive-green; Same as 265'8"-266'8" interval with diatoms and Foraminifera rare.
267'9"-268'9"	1.33	Clay, light olive-green; light olive-green slightly calcareous clay. Trace of medium-grained subrounded clear quartz sand, medium-grained dark-brown to

Depth Interval	P_2O_5 Content (%)	Lithology
		black phosphate. Diatoms and sponge spicules rare.
268'9"-269'9"	1.33	Clay, light olive-green; Same as 267'9"-268'9" interval with trace of small white limestone oolites. Diatoms and sponge spicules common.
269'9"-270'10"	0.58	Clay, light olive-green; Same as 268'9"-269'9" interval with diatoms abundant, sponge spicules common.
270'10"-271'10"	0.58	Clay, light olive-green; Same as 269'9"-270'10" interval.
271'10"-272'10"	12.3	Phosphatic sand and clay, dark greenish-brown; 40 percent very fine angular to subangular clear quartz sand, 25 percent very fine-grained dark-brown to black phosphate, 20 percent dark-gray clay, 10 percent medium subangular to subrounded clear quartz sand, 5 percent medium- to coarse-grained dark-brown to black phosphate. Trace of small dolomite rhombohedrons in slide. Sponge spicules and diatoms rare.
272'10"-273'2"	12.3	Coarse phosphatic sand and clay, dark greenish-brown; 30 percent coarse subangular to subrounded clear to frosted quartz sand, 25 percent coarse-sand to fine-gravel size particles of light-brown to black phosphate, 20 percent dark-gray clay, 15 percent medium subangular to subrounded clear quartz sand, 10 percent fine-grained light-brown to black phosphate. Trace of small dolomite rhombohedrons in slide. Foraminifera rare.
273'2"-273'9"	1.70	Phosphatic sandy limestone, light greenish-gray; 50 percent light-gray very fine-grained poorly indurated limestone, 30

Depth Interval	P_2O_5 Content (%)	Lithology
		percent light olive-green calcareous clay occurring as "patches" in limestone, 10 percent medium subangular to subrounded clear quartz sand, 10 percent medium-grained dark-brown phosphate.
273'9"-276'2"		No sample.
		Eocene - Castle Hayne Limestone
276'2"-276'11"		Shell limestone, light to dark-gray, well indurated. Approximately 60 percent of this interval consists of fossil casts and molds. Trace of angular to subrounded clear quartz sand, fine-to coarse-grained dark-brown to black phosphate. Foraminifera and Ostracoda rare.

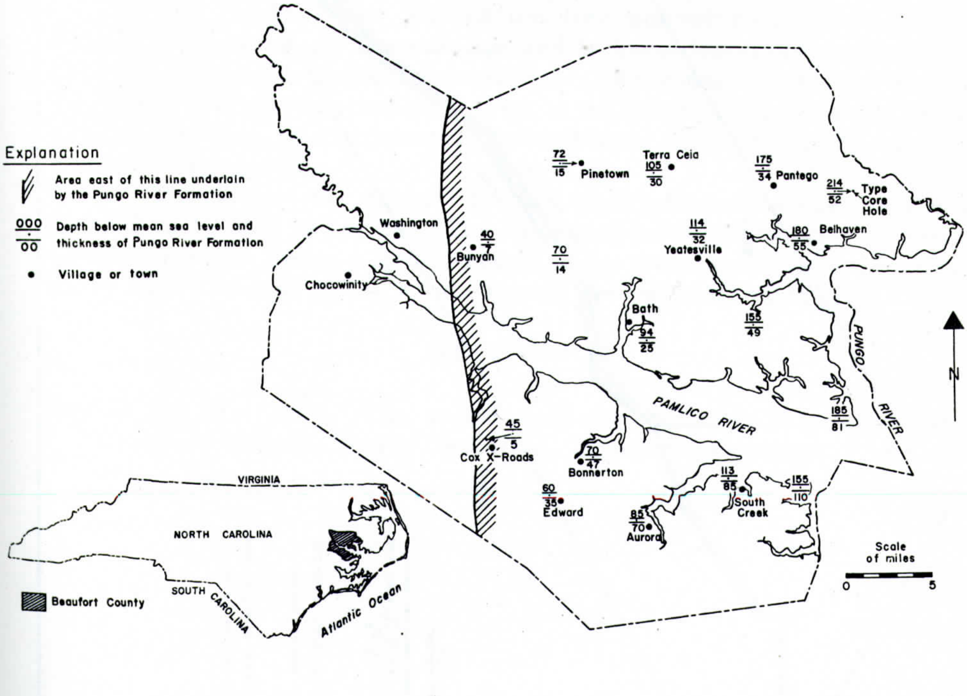


Figure 2. Map of Beaufort County showing areal extent of the Pungo River Formation.

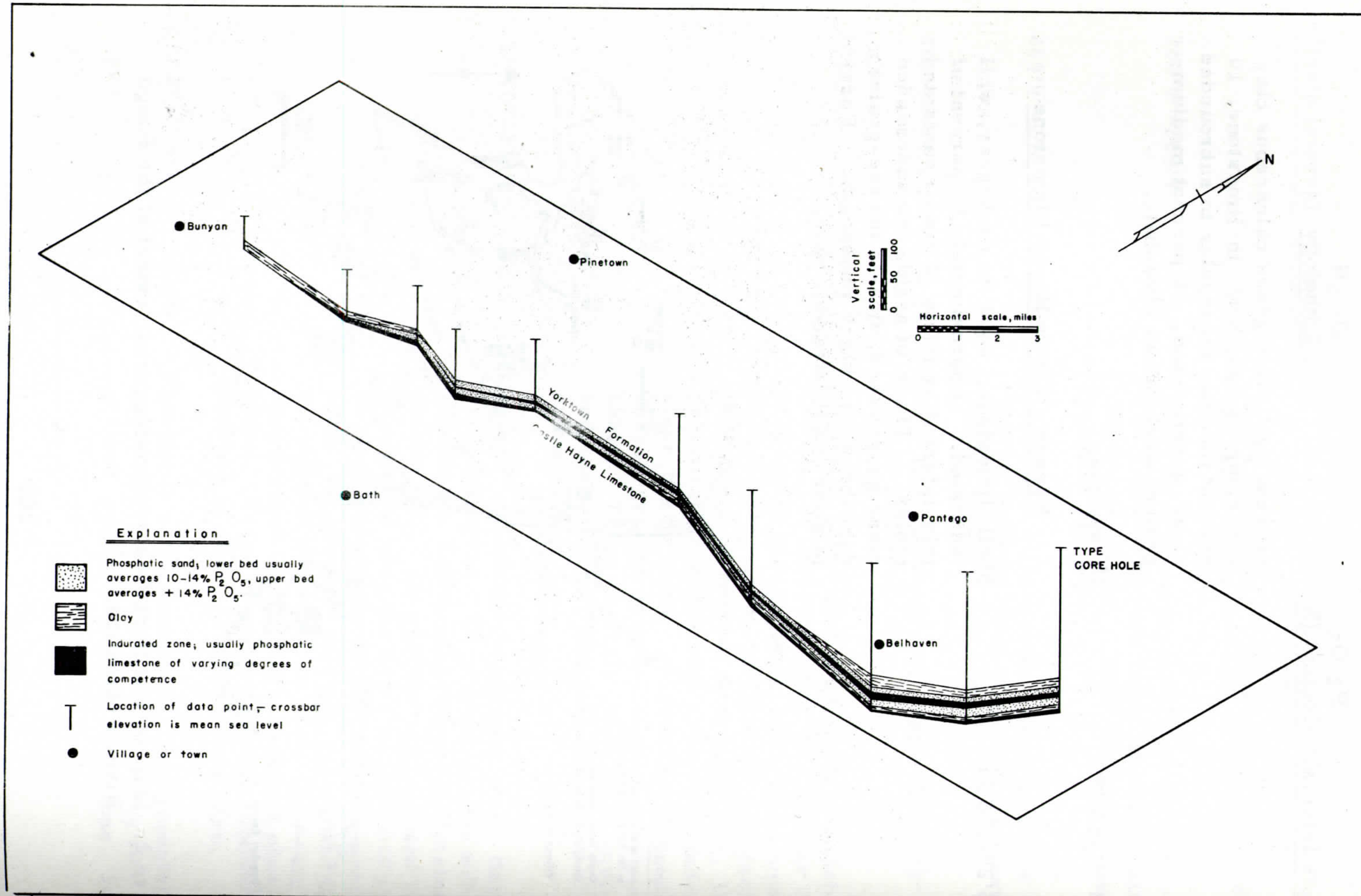


Figure 3. Typical isometric fence section of the Pungo River Formation in Beaufort County.

The Pungo River Formation underlies more than 700 square miles of the eastern part of Beaufort County (Fig. 2). Its areal extent beyond the boundaries of Beaufort County is unknown. In Beaufort County, the formation is composed of interbedded phosphatic sands, silts and clays, diatomaceous clays, and phosphatic and non-phosphatic limestones. Lithologic horizons in the formation may be traced laterally across the county. Figure 3 is a typical isometric fence section of the Pungo River Formation in the northern part of Beaufort County.

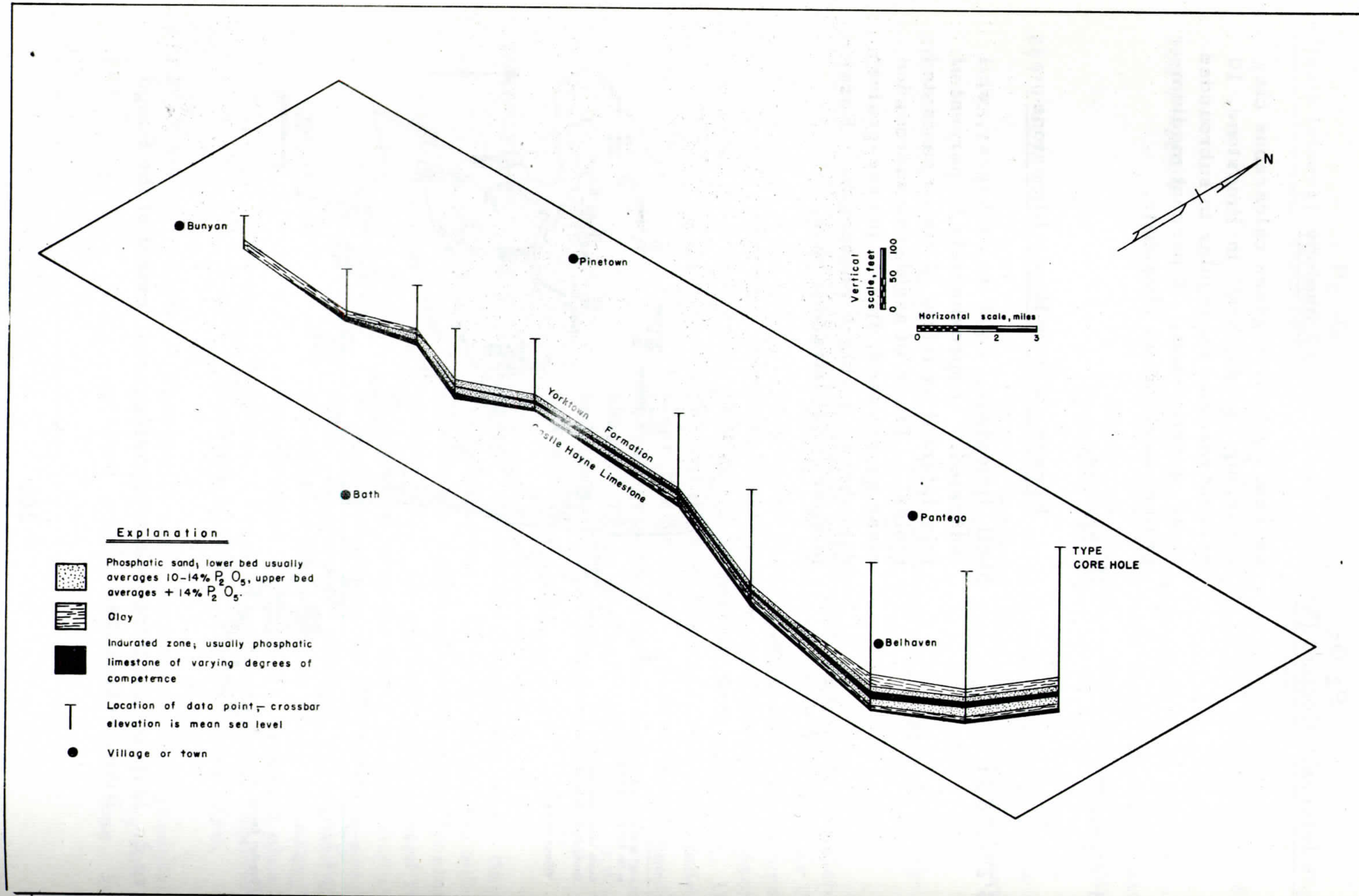
The P_2O_3 content of the phosphatic sands in the formation ranges up to a known maximum of about 21 percent of the raw core sample. They are comprised of fine- to medium-grained collophane and quartz with varying percentages of silt and clay sized material, small phosphatized fish teeth and bone fragments. The collophane grains are typically smooth, glossy, brown in color, and spheroidal to ovate in shape. Surfaces of individual grains commonly show concentric rings or bandings. The quartz occurs typically as clear, flat sided, angular to subrounded grains. Accessory minerals in the phosphatic sands include calcite and garnet. The more clayey phosphatic sands often contain weathered shell material.

The Pungo River Formation lies unconformably on the Castle Hayne Limestone of Eocene age and is unconformably overlain by the upper Miocene Yorktown Formation. The contact with the overlying Yorktown Formation, as observed in well cuttings and cores, is often gradational due to the reworked phosphatic material in the base of the Yorktown Formation.

The top of the formation dips generally to the east at a rate of about 5 to 10 feet per mile. The thickness of the formation in Beaufort County ranges from a featheredge in the western part of the county to more than 110 feet in the southeastern part of the country.

REFERENCE

Brown, P. M., 1958, The relation of phosphorites to ground water in Beaufort County, North Carolina: Economic Geology, v. 53, p. 85-101.



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AN UNUSUAL RADIOACTIVE, RARE EARTH-BEARING SULFIDE DEPOSIT IN CABARRUS COUNTY, NORTH CAROLINA*

by

Harold W. Sundelius
and
Henry Bell, III
U. S. Geological Survey

ABSTRACT

The Heglar prospect in Cabarrus County, North Carolina, contains disseminated pyrite and a significant amount of rare earth elements in an andradite-opal-chalcedony-quartz gangue. It is radioactive and occurs in an area of anomalous radioactivity. Opal commonly occurs as concentric colloform layers around fibrous chalcedony. Gold and tungsten have been mined in the area from quartz veins which have many features typical of gold-bearing quartz-pyrite lodes in the southern Piedmont. The prospect is near the boundary between pyroclastic and epiclastic rocks with interbedded volcanic flows characteristic of the Carolina slate belt to the east and plutonic rocks of the Charlotte belt to the west. It is a contact deposit associated with the intrusion of a pink microcline-bearing granite into a calcareous country rock now largely amphibolite.

INTRODUCTION

The Heglar prospect, Cabarrus County, N. C., is of interest because the associated minerals indicate a type of mineralization not previously reported in North Carolina. Disseminated pyrite in an andradite-opal-chalcedony-quartz gangue, a significant amount of cerium and other rare-earth elements, and radioactivity characterize the deposit. The prospect is in an area where gold and tungsten have been mined from quartz veins.

The Heglar prospect, near the northeast corner of the Concord SE. quadrangle (Fig. 1), is on a tributary of Hamby Branch approximately 750 feet south of the road through Cold Springs. The old Faggart gole mine, consisting of two abandoned shafts and some pits, is several hundred feet east of the prospect (Fig. 2).

*Publication authorized by the Director, U. S. Geological Survey.

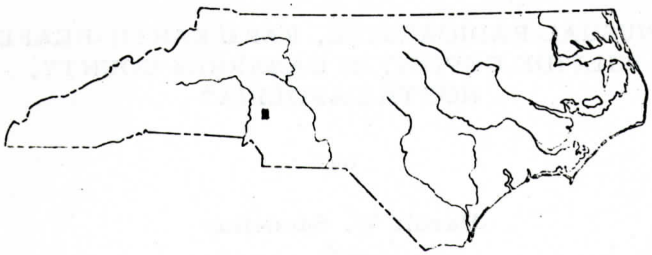

Figure 1. Index map of North Carolina showing Concord SE. quadrangle.

In the mid-1950's, Mr. A. L. Nash and his associates sank an exploratory shaft at this site on a pronounced radiometric anomaly which they had discovered by means of an airborne radioactivity survey. A subsequent airborne radiometric survey conducted by the U.S. Geological Survey shows that the anomaly extends about 3 miles to the northeast (Johnson and Bates, 1960, p. B 192-B 195). Grab samples were collected from bulldozer cuts by W. C. Overstreet and Henry Bell in 1956 and by the authors from the dump in 1962. Geologic mapping by the authors in the Concord and Mount Pleasant quadrangles is in progress, and some results of geologic work in the Concord area have been reported by Bell (1960).

REGIONAL SETTING

The Heglar prospect and the adjacent Faggart mine are part of a group of associated mines and prospects that includes the Phoenix, Furniss, Pioneer Mills, Newell, Crowell, Blackcat, and Allan Boger mines. These deposits are veins or shoots located within a few miles of each other in the Gold Hill portion of a belt of copper-gold deposits that extends from Virginia to Georgia (Pardee and Park, 1948, p. 32-50, 65-72), and have many features that are typical of the gold-bearing quartz-pyrite lodes of the southern Piedmont. They are near the boundary between rocks of the Carolina slate belt on the east, which include pyroclastic and epiclastic sediments with interbedded volcanic flows in the greenschist facies, and plutonic rocks of the Charlotte belt in the epidote-amphibolite facies. Recent lead-alpha age determinations suggest an Ordovician age for some of the slate belt rocks (White and others, 1963). Charlotte belt rocks are shown as Paleozoic (?) on the geologic map of North Carolina (Stuckey and Conrad, 1950). Northeast of the Heglar prospect the rocks of the slate belt are separated from rocks of the Charlotte belt by the Gold Hill fault, and according to Laney (1910, p. 68-72) this fault extends to the southwest through the area shown in Figure 2. The presence of this fault has not been demonstrated by reconnaissance mapping in the area, however, and the fault is not shown in Figure 2.

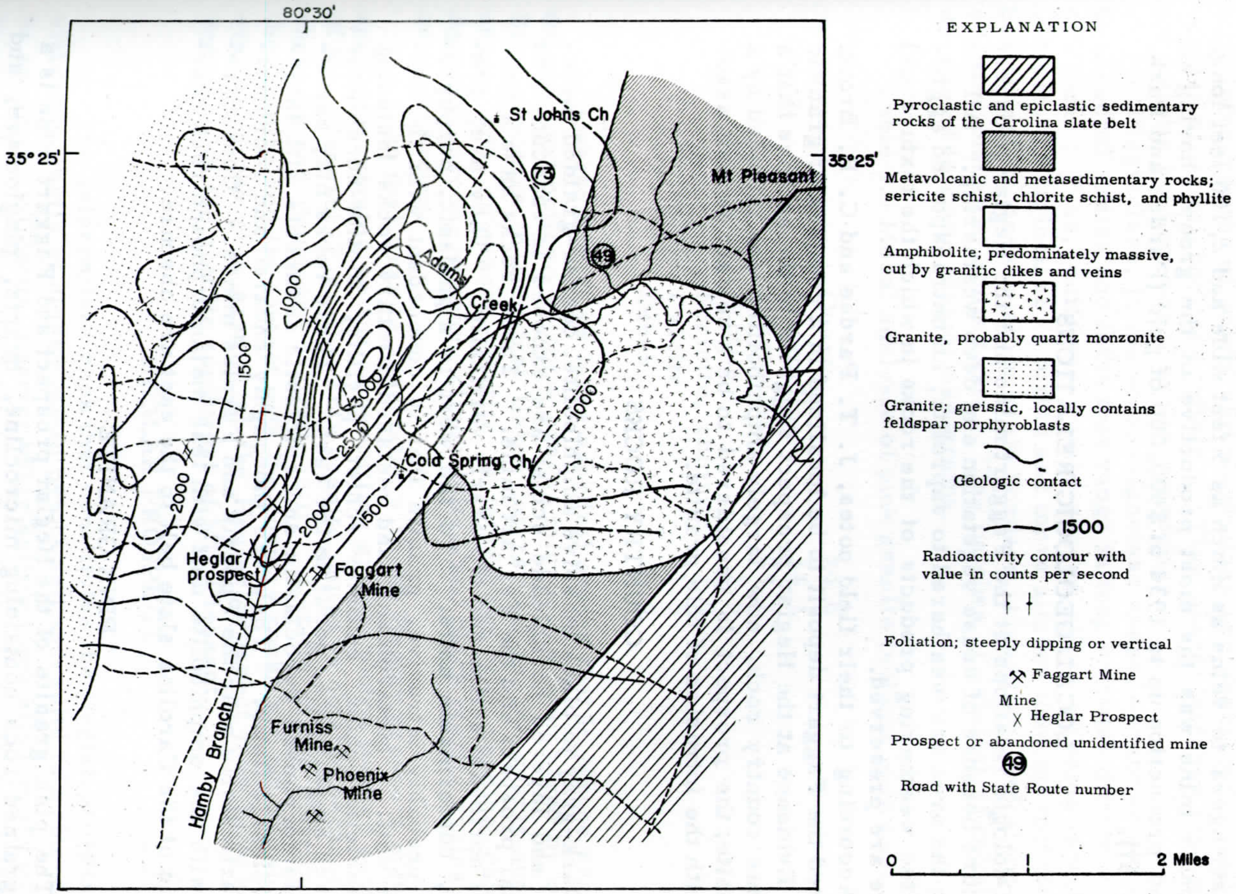

Figure 2. Geologic map showing radioactivity contours in the vicinity of the Heglar prospect. Radioactivity data contributed by R. W. Johnson and R. E. Bates.

In addition to quartz and pyrite, the deposits in the Gold Hill belt commonly contain chalcopyrite, free gold, galena, specular hematite, barite, and carbonates of the calcite-ankerite-siderite group. Locally scheelite and ferberite occur in the ore. The deposits are mineralized fractures and shear zones and range in size from discontinuous stringers to veins as much as 5 feet wide and 2,100 feet long. The Phoenix mine was the most productive of the group, having an estimated production up to 1934 of $400,000 of gold (Pardee and Park, 1948, p. 67).

LOCAL GEOLOGIC RELATIONS

Geologic relations at the Faggart mine and the Heglar prospect are obscure because of dense vegetation and deep weathering. All the rocks in the area are weathered to saprolite, an untransported aggregate of the weathering products of the rocks in which the texture and structure are preserved.

According to their field notes, J. T. Pardee and C. B. Brown considered the Faggart deposit to be localized in a complex of granitic rocks. Evidence at the Heglar prospect suggests to the authors that a calcareous country rock, now largely amphibolite, was intruded by a pink granite; the prospect is considered to be a contact deposit associated with the intrusion of this granite.

COUNTRY ROCKS

Dark-gray to black massive amphibolite, coarse-grained metadiorite, and layered hornblende schist are exposed in roadcuts near the Heglar prospect and the Faggart mine. These rocks have a predominant northeast strike and dip nearly vertically. They are, presumably, conformable units. To the west is a gneissic, porphyroblastic, probably intrusive, granite that is concordant with the amphibolite unit. Metavolcanic and metasedimentary rocks including quartz-sericite schist, chlorite schist, phyllite, biotite-hornblende schist, and amphibolite, occur to the east. These rocks may represent metamorphosed pyroclastic and epiclastic sediments with interbedded volcanic flows. They are thoroughly sheared and recrystallized, particularly near the Phoenix and Furniss mines. Contact relations with the amphibolite unit with less metamorphosed rock characteristic of the Carolina slate belt to the east are obscure.

PINK GRANITE

The pink granite of the Heglar prospect and Faggart mine is a coarse-grained rock containing microcline, quartz, plagioclase, and only a minor amount of biotite. A single modal analysis (Table 1) suggests that the rock is a quartz monzonite. A hypidomorphic-granular texture is well developed. Microcline occurs as anhedral to subhedral, nearly equant grains that range in size from 0.1 to 5 mm. Some of the microcline is micro-perthitic, and film, vein, and patch perthite were noted. Much of the perthite is uniformly distributed in films and lenses parallel to the 010 twinning. Both replacement patch perthite and film perthite due to exsolution are recognized. Myrmekitic intergrowths of quartz and plagioclase are characteristically developed along microcline borders. Tiny quartz patches and veinlets and calcite veinlets occur in the microcline.

Plagioclase, in the sodic oligoclase range, occurs as subhedral to euhedral grains and laths that range in long dimension from 0.1 mm to 2 mm. Fine, uniform, evenly spaced albite twinning is well developed. Plagioclase is turbid and more altered than the microcline. Sericitization occurs along grain borders, cleavages, and along composition planes of albite twins. Tiny patches of veinlets of calcite are developed in some plagioclase grains.

Table 1. Modal analysis of pink granite (volume percent).

Quartz	29.9
Microcline	34.1
Plagioclase	28.2
Biotite	1.5
Sericite, chlorite	3.9
Calcite	1.5
Other	0.9

Quartz occurs as large anhedral grains that in places show undulatory extinction. In some cases, microcline is embayed by quartz. Biotite occurs in euhedral flakes interstitial to the quartz and feldspars, and, in places, biotite is intergrown with pennine chlorite. Apatite, zircon, sphene, clinozoisite, and black opaque grains occur as accessories.

The pink granite associated with the Heglar prospect may be an apophysis related to the crosscutting granite pluton located southwest of Mt. Pleasant (Fig. 2). This granite pluton is notable because of the shearing and abundance of pyrite in it. Details of the distribution of the granite and its contact with the country rocks are not known, however, and the pink granite at the Heglar prospect may have no connection with the granite southwest of Mt. Pleasant.

HEGLAR PROSPECT

The mineralized rock that constitutes the Heglar prospect consists dominantly of disseminated pyrite and andradite in a fine-grained to aphanitic siliceous matrix; other sulfides and allanite are present. In places, pyrite and andradite occur in 1- to 10-mm layers alternating with fine-grained siliceous material. In gross appearance, the boundaries between layers are sharp, but in detail there is a gradual transition caused by a decrease in size and quantity of garnet and sulfides. A distinctive bleached, patchy replacement texture is well developed. The siliceous groundmass characteristically has colloform banding and botryoidal structure and has vugs partly filled with chalcedony and opal. Cataclastic texture also occurs locally.

SULFIDES

Pyrite occurs as disseminated subhedral to euhedral grains and aggregates ranging in size from 0.5 to 10 mm. Chalcopyrite, sphalerite, galena, and molybdenite occur in lesser amounts. The sulfides replace andradite along its borders, along fractures, and in irregular patches. Unreplaced andradite remnants are found within pyrite grains. Pyrite veinlets cut epidote grains, and in places, pyrite appears to replace allanite. Tiny pyrite grains also coat vugs. Some of the sulfides are fractured and cemented, veined, and partially replaced by opal and chalcedony. Chalcopyrite, the second most abundant sulfide, occurs in anhedral grains around and interstitial to pyrite. Most of the chalcopyrite is later than the pyrite.

ANDRADITE

Andradite occurs as black, nearly vitreous, subhedral to euhedral grains and aggregates ranging in size from 1 mm to 2.5 cm. Index of refraction measurements give a value of 1.879, and the cell edge as computed from the 640, 642, and 444 reflections is 12.040Å. These parameters indicate that the garnet is approximately 94 percent andradite, 4 percent grossularite, and 2 percent spessartite (Sriramadas, 1957, p. 294-298). Fine striations are well developed on some faces. Some of the andradite displays anomalous birefringence and complex twinning, and color zoning consisting of a lighter rim around a dark core is typical. Inclusions of apatite are common. Andradite is altered to chlorite and epidote along fractures and partings. The garnet is replaced along grain boundaries and fractures and in bleblike patches by opal and chalcedony. In places, there are skeletal remnants of andradite. Much of the garnet is fractures and cemented by opal and chalcedony. Sulfides also vein and replace garnet.

SILICEOUS GROUNDMASS

The fine-grained to aphanitic groundmass is composed of opal, chalcedony, and quartz. The opal is a yellow-brown to amber, resinous isotropic material that breaks characteristically with a conchoidal fracture. The index of refraction of most of the isotropic material is below 1.47. Contraction cracks locally showing poorly to moderately well developed polygonal patterns are common (Fig. 3).

Figure 3. Photomicrograph of contraction cracks in chalcedony (white, low relief); opal (gray, high negative relief) borders chalcedony. Opal and chalcedony replace andradite (dark gray to black, high relief). Plane-polarized light.

According to Brian Skinner (written communication, 1964), x-ray diffraction patterns confirm that opal is a major phase of the groundmass and indicate that an ordered low-density phase occurs with the opal. The nature of this ordered phase has been referred to in the literature as beta-cristobalite, disordered low-cristobalite, and tridymite (Sato, 1962, p. 296-305; Sun, 1962, p. 1453-1456; Franks and Swineford, 1959, p. 186-196; Florke, 1955, p. 217-223). The diffraction pattern of the ordered phase of the Heglar material resembles that of beta-cristobalite, but it is not sufficiently definitive to be designated as beta-cristobalite, and is, perhaps, better called simply opal.

Chalcedony is developed as microcrystalline radiating fibrous or feathery aggregates. Upon rotation between crossed nicols much of this ground mass material shows the black cross typical of aggregate interference (Fig. 4). Delicate color banding normal to the elongation

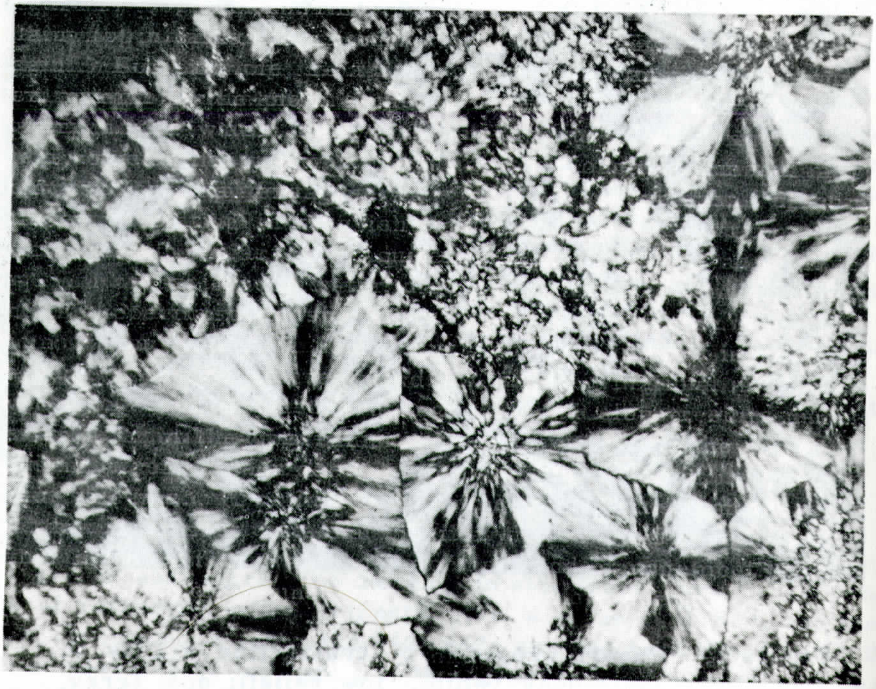

Figure 4. Photomicrograph of chalcedonic groundmass. Note spherulitic texture and aggregate polarization. Polygonal forms are due to mutual interference during growth. Crossed nicols.

of the fibers is common, and botryoidal structures are well developed, particularly in vug linings. In places, filigree, lacelike, and vermicular textures are developed in the chalcedonic material. A common feature is the concentric arrangement of opal around layered, fibrous chalcedony, which, in turn, is developed around anhedral quartz grains (Fig. 5). In places, fibrous chalcedony appears to have developed from opal. Radiating clusters of orange, acicular, birefringent chalcedonic grains occur at places in the opaline matrix. Most of the quartz occurs as micro- to cryptocrystalline anhedral grains that, in places, show undulatory extinction and sutured borders. The siliceous matrix replaces or veins andradite, sulfides, allanite,

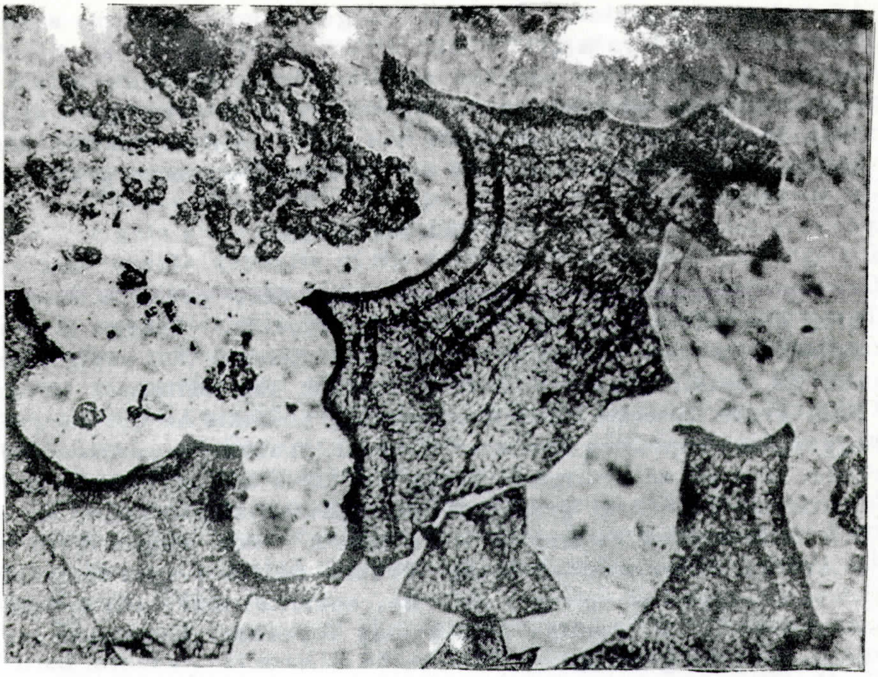

Figure 5. Photomicrograph showing colloform-banded opal (high negative relief, dark gray) and chalcedony (low relief, light gray) in silicified groundmass. Plane-polarized light.

epidote, and chlorite and is evidently the latest material to be deposited.

ALLANITE

Allanite occurs as, small black to smoky-brown, anhedral, birefringent to altered isotropic masses around epidote cores, as irregular patches replacing andradite along grain boundaries and fractures, as small remnants partially replaced by sulfides and as veinlets cutting andradite. Some of the allanite is pleochroic in shades of black, smoky brown, and dark red. Opal and microcrystalline silica veinlets cut allanite.

APATITE

Apatite occurs as small euhedral inclusions in andradite and also disseminated in the siliceous matrix. Apatite grains have apparently resisted replacement by sulfides and occur in places as remnants within pyrite grains that have partially replaced andradite. Some of the aparite presents a spongy appearance due to tiny opaque inclusions. A distinctive feature is the nearly ubiquitous narrow border around apatite grains. This rim ranges from a uniform, sharply delineated border to a girdle with embayments into the apatite. This border is distinctive between crossed nicols because it is a bright-white color in contrast to the typical low first-order gray of apatite. This border was approximately the same relief as apatite, and it extinguishes simultaneously with the surrounding apatite grains.

OTHER MINERALS

Chlorite, barite, epidote, magnetite, green biotite, actinolite, and microcline occur in small amounts. Barite is present as euhedral tabular crystals, as anhedral masses that replace andradite and as small grains scattered through the siliceous groundmass. Pale-green chlorite occurs in sparing amounts as fibrous grains and aggregates replacing a tabular mineral, probably a pyroxene or amphibole, and as an alteration along fractures and partings in andradite. Scattered subhedral grains of microperthitic microcline as much as 0.5 inch in long dimension were noted. All stages from incipient alteration of microcline along borders and cleavages to nearly complete alteration to epidote, chlorite, sericite, and black opaque grains were noted. Microcline grains may represent unreplaced inclusions from the pink granite.

PARAGENESIS

A general paragenetic sequence based on replacement textures and veining relationships is given in Table 2. The sequence is the development of contact calc-silicate minerals, followed by sulfide mineralization, and concluded by low-temperature silification.

Table 2. Generalized paragenetic sequence.

Early → Late

apatite
andradite
magnetite
epidote, allanite
pyrite
chalcopyrite
barite
opal, chalcedony

SPECTROGRAPHIC ANALYSES

Semiquantitative spectrographic analyses of four grab samples from the dump at the Heglar prospect are given in Table 3. These analyses were made by Helen W. Worthing of the U. S. Geological

Survey. The analyses show noteworthy amounts of the rare-earth elements, also molybdenum, silver, copper, lead, zinc and bismuth.

The combined content of cerium, lanthanum, praseodymium, and neodymium ranges from 0.14 to 0.42 percent. The rare-earth elements probably occur in allanite, but a part may be incorporated in apatite. Pardee and Park (1948, p. 38, 43) report the occurrence of allanite in a gold placer and lode deposits in Georgia but not elsewhere in the gold-quartz deposits of the southern Piedmont. A large proportion of cerium earths (Ce, La, Nd) in relation to ytterium earths (Y, Yb) is characteristic of some rare earth deposits associated with alkalic rocks. Two large masses of syenite forming a ring structure and dikes of syenite and other alkalic rocks occur in the northwest corner of the Concord SE quadrangle and in the Concord quadrangle to the north (Bell and Overstreet, 1959). None of these rocks have been found near the Neglar prospect, however.

The molybdenum content of the samples is attributable to molybdenite which has been identified in polished surfaces and by X-ray powder pattern. It is also reported to occur at the Pioneer Mills mine nearby (Genth, 1891, p. 23).

The silver content of the samples cannot be attributed to an identified mineral. It may be associated with undetected gold. Gold occurs at the Faggart mine nearby and in gravel collected in Hamby Branch a short distance below the Heglar prospect and the Faggart mine.

Bismuch-bearing minerals have not been recognized in samples from the Heglar prospect. Genth, however, reports (1891, p. 22) bismuthinite at Gold Hil and tetradymite at a number of mines in the group associated with the Heglar prospect, including the Phoenix mine, Boger (Allan Boger ?), and Gold Hill mines. Very fine grained bismuthinite or a bismuth-bearing telluride may not have been detected in the samples. Tellurium concentrations below 0.01 percent would not ordinarily be detected by semiquantitative spectrographic analyses.

A heavy-mineral concentrate panned from gravel collected in Hamby Branch not far below the Heglar prospect contains abundant scheelite (Overstreet and Bell, 1960). Spectrographic analysis of this heavy-mineral concentrate from which magnetite was removed showed that the samples contained 0.015 percent tungsten. Neither scheelite nor ferberite, minerals which have been found in associated mines, were seen in the samples examined from the Heglar prospect, and tungsten is not reported in the spectrographic analyses shown in Table 3.

RADIOACTIVITY

The deposit is located within a northeast-trending radiometric anomaly charted by airborne methods (Johnson and Bates, 1960). The anomaly is developed along the western border of the granite body southwest of Mount Pleasant (Fig. 2). The anomaly ranges from 1,500

Table 3. Semiquantitative spectrographic analyses of four grab samples of mineralized rock from the Heglar prospect. Elements that occur in significant amounts are underlined. Helen W. Worthing, U. S. Geological Survey, analyst.

Weight percent	56-OT-1	56-OT-2	56-OT-3	56-OT-4
More than 10%	Si	Si, Fe	Si, Fe	Si, Fe
7%	Fe		Ca	
5%		Ca		Ca
3%	Ca			
1%		Pb		
0.7%	Al, P	Al		
0.5%		Zn	Al, K	Al, K, Cu
0.3%	K, Pb, Zn	K, P		
0.2%		Cu		
0.15%	Mg, Ce, Cu, La	Mg	Mg, P, Cu	Mg, P
0.1%	Nd	Ce, La, Nd		
0.07%	Mn	Mn	Mn, Ce, La, Nd	Mn, Ce, La, Nd
0.05%		Ti		
0.03%	Na, Ti	Na, Bi		
0.02%	Ba, Bi, Sr	Sr	Ti, Pb, V	Na, Ti, V
0.015%	Pr	Ba, V		Co
0.01%	Mo, Ni	Pr	Na, Sr	Ba, Sr
0.007%	Co, V, Y, Sm	Co, Mo, Ni, Y	Co, Nb, Y	
0.005%	Nb, Zr	Ag, Nb, Sm		Nb, Y
0.003%		Zr	Mo, Ni	Ni, Zr
0.002%	Sc		Ba, Zr	Mo
0.0015%	Ag	Cr, Ga	Ga	Ga
0.001%	Cr, Ga	Sc		
0.0007%	Yb	Yb	Cr, Sc, Yb	Cr, Sc
0.0005%		Sn	Sn	Sn, Yb
0.0003%			Ag	Ag
0.0002%	Be			
0.0001%		Be	Be	Be

Looked for but not detected: All samples, As, Au, B, Cd, Ge, Hf, Hg, In, Li, Pd, Pt, Re, Sb, Ta, Te, Th, Tl, U, W, Eu, Gd, Tb, Dy, Ho, Er, Tm, Lu. Samples 56-OT-1, Sn. Sample 56-OT-3, Zn. Sample 56-OT-4, Bi, Zn, Pr, Sm.

Results are reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1, etc., which represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30% of the time.

to 3,250 counts per second. The radioactivity of the deposit was verified on the ground with a scintillometer. No minerals with uranium or thorium as a major constituent have been recognized in the mineral-ized rock, and no uranium or thorium were reported in the semiquanti-tative spectrographic analyses. Allanite is reported to contain from 0.35 to 2.23 percent thorium (Deer, Howie, and Zussman, 1962, p. 213), and the radioactivity associated with the deposit may be due to residual weathering products of allanite. The cerium rare earths are commonly removed from allanite during weathering (Watson, 1917, p. 491-498), and the thorium content is increased relatively. Allanite de-velops a reddish brown earthy crust that contains ferric hydroxide and closely resembles other iron oxide weathering products in areas of deep weathering. In Georgia, Silver and Grunefelder, (1957, p. 1796) report that alteration products of allanite include bastnasite, huttonite (?), hematite and a pale yellow isotropic or nearly isotropic mineral. Further mapping and sampling will be necessary to discover the sig-nificance of the position of the deposit relative to the radiometric anomaly and to test for the weathering products of allanite.

SUMMARY AND CONCLUSIONS

The Heglar prospect is in a group of associated mines and pros-pects near the boundary between rocks of the Carolina slate belt in the greenschist metamorphic facies and higher grade metamorphic rocks in the Charlotte belt. The associated mines and prospects are on gold-quartz veins typical of deposits in the Gold Hill belt of the southern Appalachians. They have pyrite, chalcopyrite, barite, molybdenite, gold, and probably some bismuth mineral in common with the deposit at the Heglar prospect. The deposit at the Heglar prospect, however, has some unusual features not shared by the others. It is a replace-ment deposit at the contact of a pink microcline-bearing granitic rock and amphibolite. The mineral assemblage consists of the calc-sili-cates, andradite, epidote, and allanite, with magnetite and apatite, sulfides, mainly pyrite and chalcopyrite, and a late opal-chalcedony-quartz replacement gangue. The cerium rare earths are unusually a-bundant, and the deposit is radioactive.

Association of the low-temperature products of silicification such as opal and chalcedony at the Heglar prospect within a group of deposits generally characteristic of mesothermal deposition suggests that locally introduction of mineralizing solutions took place over a significant range of temperature. Preservation of delicate colloform structure and the generally undeformed character of the mineralized rock at the Heglar prospect indicates that mineralization post-dated pervasive regional metamorphism. The presence of strongly sheared rocks and a probable late crosscutting granite associated with radio-activity, gold-quartz-base metal and tungsten mineralization and a significant quantity of rare-earths suggests that the area merits care-ful search for other deposits with mineralogy atypical of this region.

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THE ELBERTON BATHOLITH

by

Lawrence D. Ramspott
University of Georgia

ABSTRACT

The Elberton batholith constitutes over 900 square miles of the east-central Georgia Piedmont. It consists of fine-grained adamellite and porphyritic adamellite. The overall cross-cutting aspects, the presence of inclusions of metamorphic country rock, and the position with respect to metamorphic zones suggest a late- or post-tectonic origin. Mica age determinations give values of 250 m.y., while zircon results are on the order of 450 m.y. The Elberton batholith is asymmetrically placed to the southeast side of the belt of maximum metamorphic intensity. The rift and catacliastic eatures of the pluton, together with the discordance of the K-A ages and Pb-U ages, suggest that the batholith has been metamorphosed following emplacement into previously metamorphosed country rock.

INTRODUCTION

Granitic rocks constitute over 900 square miles of the Piedmont of east-central Georgia, underlying large parts of Elbert, Oglethorpe, Greene, Hancock, Wilkes, and Lincoln Counties. The town of Elberton is situated in the midst of this granitic rock mass and is the center of a large monument industry. At least forty quarries are located near Elberton in Elbert and Oglethorpe Counties.

Much of what is shown on the Geologic Map of Georgia as granite is instead migmatite, or even gneiss and schist. However, bodies of granite which are now shown on the state map are known to exist.

Following Watson's study (1902) of the granites and gneisses of Georgia, scattered knowledge accumulated concerning Georgia granitic rocks. Much of this information is unpublished. As part of a study of the Elberton batholith (NSF grant GP-2143), all information known to the writer concerning the batholith was compiled and summarized in the following paper. Because much of this information is scattered or unpublished, this summary will be of some use while further knowledge accumulates.

PETROGRAPHY

The Elberton batholith is composed of a number of individual

Table 1. Modes of Elberton batholith granites
(Vernon J. Hurst, previously unpublished)

Sample #	1	2	3	4	5	6	7	8	13	14	15	7V3-5	7V7	7Z1-0
Quartz	30.2	30.2	30.7	30.6	29.1	31.8	28.4	24.6	24.4	26.7	27.0	34.3	32.9	28.3
K-Feldspar	28.3	30.9	36.4	24.9	30.4	31.5	31.8	31.6	21.5	31.3	33.8	28.0	19.5	35.5
Plagioclase	31.5	30.1	27.7	35.6	33.5	31.2	30.5	35.5	38.9	35.3	31.4	36.6	37.2	28.2
Biotite	3.8	6.9	4.2	4.1	5.1	4.5	6.8	6.7	9.1	5.3	5.7	0.6	9.1	5.2
Muscovite	4.9	0.7	0.1	4.1	1.5	0.4	0.8	1.2	4.5	0.4	0.5	0.3	0.2	2.4
Chlorite	0.4	0.1	0.1	0.2	--	0.1	0.4	--	--	--	0.1	0.2	0.6	0.2
Opaque Access.	0.4	0.4	0.5	0.2	0.3	0.1	0.8	0.2	0.8	0.6	0.9	tr	0.2	0.2
Trans. Access.	0.5	0.7	0.3	0.3	0.1	0.4	0.5	0.2	0.8	0.4	0.6	--	0.3	--

\# 1 - Hoover Granite Quarry, Oglethorpe Co., Gray, Fine to medium grained granite.
\# 2 - Robin Blue Quarry, Elbert Co., Gray, Fine to medium grained granite.
\# 3 - Liberty Granite Co., Oglethorpe Co., Gray, Fine to medium grained granite.
\# 4 - Harmony Blue Granite Quarry, Oglethorpe Co., Gray, Fine to medium grained granite.
\# 5 - Dixie Granite Quarry, Oglethorpe Co., Gray, Fine to medium grained granite.
\# 6 - Continental Granite Co., Elbert Co., Gray, Fine to medium grained granite.
\# 7 - Hedquist Granite Quarry, Acme Granite Co., Elbert Co., Pinkish, Fine to medium grained granite.
\# 8 - Hedquist Granite Quarry, Acme Granite Co., Elbert Co., Gray, Fine to medium grained granite.
\# 13 - Harper's Quarry, Elbert Co., Gray, Fine to medium grained granite.
\# 14 - Elbert Granite Industries Quarry, Elbert Co., Pinkish, medium grained.
\# 15 - Elbert Granite Industries Quarry, Elbert Co., Gray, medium grained.
7V3-5 Average of 3 samples, 3 miles north of Sparta, Hancock Co., Pink, coarse-grained.
7V7 Weston-Brooker Quarry, Camak, Warren Co., coarse-grained.
7Z1-0 Average of 2 samples, Drake Granite Co., Elbert Co.

bodies of pink to gray, fine- to medium-grained, equigranular or porphyritic adamellite. (The term granitic rock is applied only in the general sense.) The color index ranges from 5 to 10.

Mineralogy

The major minerals are quartz, microcline, and oligoclase in roughly equal amounts. The characteristic varietal mineral is biotite, but in many localities muscovite is well-developed. Magnetite, apatite, and zircon are ubiquitous. Allanite is a common accessory. Chlorite, hematite, and epidote are common secondary minerals.

Chayes (1951) showed 33 modes of specimens from quarries in Elbert and Oglethorpe Counties. Plagioclase, potash feldspar and quartz are nearly equal in amount, and the modes are closely grouped. Chayes found that the fine-grained Elberton rocks are distinctly lower in plagioclase than the coarse-grained Salisbury and Mt. Airy granitic rocks from North Carolina.

Unpublished modes by V. J. Hurst (Table 1) for 16 specimens from the Elberton area closely resemble Chayes' data. In only two of the modes is potash feldspar significantly in excess of plagioclase. All of the 49 modes of Chayes and Hurst fall in the adamellite (quartz monzonite) range.

An interesting study by Hurst (1953) of heavy mineral concentrates from Elberton granite-saprolite showed magnetite to be the characteristic heavy mineral. Also found were hematite, chlorite, epidote, garnet, sillimanite, staurolite, and altered ferromagnesian minerals.

Nearly all thin sections of the Elberton granitic rocks show quadrille twinning of the potash feldspar. Most of them also show simple (monoclinic) twinning. The degree of development of quadrill twinning is variable; in some specimens a majority of grains show it, in others only a scattered few.

Watson (1902) reported that microperthite commonly occurred in these rocks. In specimens examined by the writer from 13 localities, exsolved lamellae are rare, and the potash feldspar is probably microcline cryptoperthite.

Watson (1902, p. 214) noted an essentially one-feldspar (perthite) granite from the Oglesby area, but there are no other reports of one-feldspar rocks.

Texture

Both equigranular and porphyritic rocks are found in the Elberton batholith. The commonly quarried rock is fine to medium grained (0.5 to 2 mm), seriate, and xenomorphic granular. Irregular mutual penetration of the boundaries of mineral grains is common. Quartz commonly shows strain effects.

The occurrence of xenomorphic-granular (aplitic) texture instead of the supposedly more common "granitic" (hypidiomorphic-granular) texture is probably a factor in the good working quality of stone from the Elberton district.

Porphyritic rocks are rather restricted in Elbert and Oglethorpe Counties, but common in counties to the south and east. The rocks are not true porphyries in the sense of containing intratelluric phenocrysts, a feature recognized by Watson (1902, p. 272). He concluded that the potash feldspar megacrysts grew in place because of their poikilitic texture, lack of orientation, and absence of corrosion effects. Watson also suggested that gradational field relations of porphyritic and non-porphyritic rocks support this conclusion.

A fact observed, but not emphasized, by Watson is that microcline in the fine-grained rocks is also commonly poikilitic. Qualitatively, the mineralogy of the porphyritic rocks and the non-porphyritic rocks is very similar. The porphyritic granitic rocks of Georgia are probably a result of the late stage growth of potash feldspar and likely differ from the non-porphyritic granitic rocks only in the distribution of potash feldspar. They definitely do not indicate hypabyssal conditions or variation in rate of crystallization.

A faint mineral parallelism can be seen in nearly all specimens. Both foliation (biotite alignment) and lineation (feldspar alignment, mineral "streaks) occur. Schlieren are found locally; in some cases to such an extent that a quarry or section of a quarry must be abandoned.

STRUCTURE

The granitic rocks of east-central Georgia have a cross-cutting relationship with the surrounding rocks (Watson, 1902, p. 264; Grant, 1958, p. 39; Crickmany, 1952, p. 41).

Watson (1902, p. 265) remarked on the absence of definite inclusions although he reported segregations as numerous. Ramspott (1964) reported on inclusions from a quarry in Elberton. These inclusions are aligned and there is no preferred orientation of foliation in the inclusions. Furthermore there are examples of early inclusions contained within later ones. In this one quarry, evidence for a mobile magma is very clear.

Many of the quarries in the Elberton area are remarkably free from jointing and sheeting. Although jointing is not well-developed, there are preferential planes along which the rock breaks easily. As in other granite districts, the directions of easiest parting consist of three mutually perpendicular planes. The direction of easiest parting in the Elberton area is sub-horizontal and is termed the "rift". The sub-vertical directions are termed the "run" and "grain". This terminology is a local variation of the rift-grain-hardway terminology reported by Balk (1937).

The regional orientation of the sub-vertical partings is non-uniform, although quarries in a local area have a uniform orientation. The writer is presently engaged in a study of this orientation. As far as can be told from preliminary observations, there is no relationship between lineation, foliation, schilieren, or even pegmatite veins and the directions of ease of parting. This is in accord with the conclusion reached by Balk (1937, p. 22) that the Appalachian granitic rocks furnish examples of the superposition of rift after development of mineral parallelism. Watson early recognized that "since the intrusion of the last granites, the region has suffered profound dynamometamorphism." (1902, p. 280).

The granitic rocks are commonly faulted. Amount of movement cannot be determined in most cases, but the direction of latest movement can be ascertained by the ridging on slickensided surfaces.

Slickensided fault surfaces are commonly mineralized. Locally, pegmatite veins are slickensided along one side.

Faulting must have been spread over a considerable time. Inclusions in the Acme Quarry have faults <u>within</u> the inclusions (Ramspott, 1964). In the Berkley Blue Quarry, Oglethorpe Co., a diabase dike which cuts through the quarry is offset by a fault. It is likely that movement along these faults was very slight; the offset of the diabase in the Berkley Quarry is about one foot.

AGE

Relative Age

The Elberton batholith has been regarded as Paleozoic by most workers. Diabase dikes, believed to correlate with the Triassic dikes of Connecticut and New Jersey (Lester and Allen, 1950), cut the batholith. The batholith cross-cuts all other Piedmont rocks. However, the Piedmont rocks have not been convincingly correlated with the relative geologic time scale.

Absolute Age

Absolute age determinations for Elberton granitic rocks are shown in Table 2. Age determinations on zircon concentrates by Uranium-lead methods yield ages on the order of 450 million years, whereas K/A and Rb/Sr determinations on micas yield ages on the order of 250 million years.

Grunenfelder and Silver (1958) attributed this difference to the occurrence of "two or more profound and distinct igneous or metamorphic episodes in the histories of these granite masses....". They attribute the older ages to a late Cambrian (?) plutonic episode previously unrecognized. According to this interpretation, the latest (250 m.y.) event would have affected the zircon only slightly while resetting the "atomic clock" for micas and feldspars.

Table 2. Absolute Age of Elberton Granites

Specimen #	Age (m.y.)	Method	Mineral	Laboratory	Reference
3177	254 ± 13	Rb-Sr.	Biotite	M.I.T.	Pinson, et. al., 1957
3177	245 ± 13	Rb-Sr.	Muscovite	M.I.T.	Pinson, et. al., 1957
3177	345 ± 20	K-A	Biotite	M.I.T.	Pinson, et. al., 1957
L-125	247 ± 9	K-A	Biotite	Lamont	Long, et. al., 1959
Granite	450	U^{238}/Pb^{206}	Zircon	Cal. Tech.	Gruenenfelder & Silver, 1958
Granite	455	U^{235}/Pb^{207}	Zircon	Cal. Tech.	Gruenenfelder & Silver, 1958
Granite	465	$Pb^{207}Pb^{206}$	Zircon	Cal. Tech.	Gruenenfelder & Silver, 1958
Granite	375	Th^{232}/Pb^{208}	Zircon	Cal. Tech.	Gruenenfelder & Silver, 1958
Saprolite	490	U^{238}/Pb^{206}	Zircon	Cal. Tech.	Gruenenfelder & Silver, 1958
Saprolite	480	U^{235}/Pb^{207}	Zircon	Cal. Tech.	Gruenenfelder & Silver, 1958
Saprolite	415	Pb^{207}/Pb^{206}	Zircon	Cal. Tech.	Gruenenfelder & Silver, 1958
Saprolite	380	Th^{232}/Pb^{208}	Zircon	Cal. Tech.	Gruenenfelder & Silver, 1958

An alternate interpretation is that the Elberton batholith could have originated by anatexis of the surrounding gneiss, with the zircon derived from the gneiss. Thus the "true" age of the batholith would be 250-300 million years.

Relation to Metamorphism

The following relationships are pertinent to the study of the Elberton batholith:

(1) The Elberton batholith cross-cuts the surrounding metamorphic rocks (Crickmay, 1952, p. 44; Watson, 1902, p. 264).

(2) Locally, the granitic rock contains inclusions of metamorphic county rock (Ramspott, 1964).

(3) The metamorphic rocks of the Georgia Piedmont show evidence of two distinct periods of metamorphism (Crickmay, 1952, p. 50).

(4) The Elberton granitic rocks show evidence of a post-emplacement dynamic metamorphism (Watson, 1902, p. 278).

(5) Allanite in the Elberton granites has been altered, not by metamictization, but by deuteric (?) alteration (Silver and Gruenenfelder, 1957).

(6) The Elberton batholith is not situated along the belt of maximum metamorphic intensity, but is asymmetrically placed to the southeast side. (V. J. Hurst, pers. Comm.).

The Elberton batholith followed a period of metamorphism, but either coincides with or predates a final metamorphism. The final metamorphism appears to have been more dynamic than thermal in nature. Most interesting of these relationships are Hurst's unpublished data indicating that the batholith was not a center of the regional metamorphism; but lies well on southeast side of the "hot belt".

The known distribution of rock types does not preclude the possibility of several ages of rock within the batholith. In some quarries, two types of granitic rock have a well-defined contact. Detailed mapping may reveal temporally distinct units.

The relationship of the batholith to the second metamorphism is uncertain. Although the granitic rock shows signs of deformation in almost all thin sections, this strain may relate to the late stages of emplacement. The rift directions do not appear to coincide with primary structures in the batholith. Careful study of rift directions should reveal whether the rift was impressed on the granitic rock during consolidation or whether it is a regional effect of a late metamorphism.

Tectonic Relations

Buddington (1959) defined the zone of emplacement of plutons primarily on the basis of metamorphic facies of the surrounding rocks. By this criterion, the Elberton batholith would be a catazonal pluton, because the surrounding rocks are high grade sillimanite schist and gneiss.

However, catazonal plutons are usually interpreted as being of syntectonic origin. The general cross-cutting relationships, asymmetry with regard to the "hot belt" of metamorphism, and inclusion relations are features which suggest a post-tectonic origin for the Elberton batholith.

The writer's preliminary observations in the field indicate that the individual units of the batholith may be more concordant than previously thought. Possibly there are both syntectonic and post-tectonic plutons in the batholith. Detailed mapping of the batholith may reveal its tectonic role.

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